# Refrigeration and Air-Conditioning Technology Roadmap 2050

2020 Roadmap Development Working Group Report

May 2021

Japan Society of Refrigerating and Air-Conditioning Engineers (JSRAE)

JSRAE

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# 1. Overview

# Background and Purpose of Roadmap Development

In recent years, the industrial environment surrounding refrigeration and air-conditioning technology has changed significantly worldwide. In 2015, the Sustainable Development Goals (SDGs) were announced by the United Nations, requesting all relevant stakeholders to contribute to solving societal issues by 2030. Furthermore, in 2020, the Government of Japan declared the realization of a green society, setting the national goal of carbon neutrality to reduce greenhouse gas emissions to zero as a whole by 2050.

Refrigeration and air-conditioning technology is expected to play an important role to contribute to achieve these goals by maximizing the introduction of renewable energy into refrigeration and air-conditioning technology and developing next-generation refrigerants. There is a strong demand in Japan and beyond for building a foundation to accelerate innovation by strengthening cooperation between industry, academia, government and professional associations, underpinned by the national energy efficiency technology strategy.

The 2020 Roadmap Development Working Group has been established within JSRAE in 2020 as an initiative to produce and update an industry-level roadmap on an annual basis, building a shared vision for 2050 and proposing technology development themes and directions.

Two societal areas were identified as the main scope of the roadmap. One area focuses on food loss and waste issues concerned with refrigeration technology management from production to consumption aiming to improve effectiveness and efficiency of cold chain, and the other on global warming issues concerned with air-conditioning technology management for energy supply and demand control in our society.

# Key Technological Areas for Technology Roadmap 2050

| Food Technology |
|---|
| Cold Chain |
| Food Freezing |

| Refrigerant Technology |
|---|
| Refrigerants |
| Database |
| Thermodynamic Property Table |
| JARef |

| Heat Exchanger Technology |
|---|
| Heat Exchanger |
| Fin-and-Tube Heat Exchanger |
| Shell-and-Tube Heat Exchanger |
| Plate Heat Exchanger |
| Microchannel Heat Exchanger |
| Condenser |
| Evaporator |
| Heat Transfer Enhancement |

| Next-generation technologies of refrigeration and air-conditioning system |
|---|
| Next-generation technologies of refrigeration system |
| Control of vapor compression refrigeration cycle |
| Sensing system, actuator and control system for new refrigerants and mildly flammable refrigerants |
| Cycle control methods of HEMS and BEMS |
| Separate sensible and latent cooling air-conditioning system |

| Compression Technology |
|---|
| Compressor |
| Reciprocating Compressor |
| Rotary Compressor |
| Scroll Compressor |
| Screw Compressor |
| Expander |
| Refrigeration Oil |
| Lubrication |

| Frost and Defrost Technologies |
|---|
| Frost Formation |
| Defrost |
| Heat Exchanger |
| Phase Change |
| Heat Pump |

| Desiccant, Adsorption, Absorption and Chemical technologies |
|---|
| Adsorption and Sorption |
| Desiccant air-conditioning |
| Adsorption chiller |
| Dehumidification |
| Waste heat utilization |
| Solar heat utilization |

# Overview of 2020 Roadmap Development Working Group Activities

○ **Roadmapping Workshop 1**
- Date and Time: 15:00-17:00 on 8th October 2020
- Purpose: Assumption Setting and Identification of Societal Issues

○ **Roadmapping Workshop 2**
- Date and Time: 13:00-15:00 on 27th October 2020
- Purpose: Identification of Technological Issues and Suggestions of Solutions

○ **Roadmapping Workshop 3**
- Date and Time: 13:00-15:00 on 13th November 2020
- Purpose: Value Proposition of Suggested Solutions

○ **Roadmapping Workshop 4**
- Date and Time: 13:00-15:00 on 27th November 2020
- Purpose: Identification of Support Needed from the Government of Japan to Realise the Suggested Solutions

○ **Roadmapping Workshop 5**
- Date and Time: 10:00-12:00 on 4th December 2020
- Purpose: 2050 Vision Building to Contribute to Carbon Neutrality

○ **Roadmapping Workshop 6**
- Date and Time: 13:00-15:00 on 14th January 2021
- Purpose: Overall Discussions regarding the Outputs among Workshop Participants

○ **Roadmapping Workshop 7**
- Date and Time: 15:00-17:00 on 28th January 2021
- Purpose: Review Session with the JSRAE Board of Directors and Auditors to Reflect their Feedback in the Final Outputs

# 2. 2050 Vision

# 2050 Vision

A carbon neutral era, in which the shift from fossil fuel-derived energy to renewable energy, refrigerant recovery and reuse is being promoted

Development of products and services that utilize hydrogen, fuel cells and magnetic refrigeration technology to improve the efficiency of hydrogen liquefaction, are considered to be one of the new options. In addition, maximum energy efficiency by spread of Smart Factory, ZEB, ZEH, etc. will be realized by introducing information and communication technology (ICT), using artificial intelligence (AI) and the Internet of Things (IoT).

To achieve this vision, Japan will take a leadership role, with technological capabilities and social infrastructure, for the integration of standards and regulations globally to seamlessly develop products and services with low environmental burdens.

# 3. Technological Contributions to 2050 Vision

# Technological Contributions to 2050 Vision

| | |
|---|---|
| Food Technology | • Food loss reduction by cold chain<br>• Food production optimization<br>• Energy consumption reduction by establishing hygiene standards |
| Refrigerant Technology | • Lowering of Global Warming Potential (GWP) of refrigerants, and use of natural refrigerants<br>• Promotion of refrigerant recovery and reuse<br>• Development of new refrigerants for expanding heat pump applications |
| Compression Technology | • Efficiency improvement of compressors<br>• Compressors compatible with new refrigerants<br>• Environment burden reduction through improved compressors with low GWP and natural refrigerants |
| Heat Exchanger, Frost and Defrost Technologies | • Dissemination of high efficiency systems by improving heat exchange performance and reducing heat loss due to frost formation and defrosting |
| Next-generation Technologies of Refrigeration and Air-conditioning System, and Desiccant, Adsorption, Absorption and Chemical Technologies | • Environmental load reduction by next-generation refrigeration and air-conditioning technologies (absorption, adsorption, thermal storage technology, etc.) that actively utilizes renewable energy.<br>• Widespread use of residential and industrial heat pump system to enable high-temperature heat generation. |

# 4. Technology Roadmap 2050 (2020 Edition)

# Technology Roadmap 2050 (2020 Edition)

| 2021 | 2025 | 2030 | 2040 | 2050 | Vision |
|---|---|---|---|---|---|

## Food Technology

- Establishment of food freezing and cold chain technology that complies with hygiene standards (to 2030)
- Establishment of quality evaluation model that can comprehensively evaluate from freezing, thawing to consumption (to 2030)
- Visualization of the optimum value (optimal energy amount) for total engineering in food freezing and cold chain (to 2030)

2030–2050:
- Food loss reduction by cold chain
- Food production optimization
- Reduction of energy consumption by establishing hygiene standards

## Refrigerant Technology

- Search and development of new refrigerants (to 2030)
- Full utilization of existing refrigerants and expansion of applications due to deregulation (to 2030)
- Emission reduction by promoting refrigerant recovery (to 2030)
- Search and development of refrigerants suitable for high-temperature heat pumps (to 2040)
- Clarification of thermophysical properties and establishment of equation of state (to 2040)
- Evaluation of thermodynamic performance and selection of suitable heat pump cycle (to 2040)
- Evaluation of compatibility with various materials and lubricant oil (to 2040)

2030/2040–2050:
- Lowering the Global Warming Potential (GWP) of refrigerants, and use of natural refrigerants
- Promotion of refrigeration recovery and reuse
- Development of new refrigerants for expanding applications of heat pumps

## Compression Technology

- Efficiency improvement of compressors (to 2040)
- Adaptation to various refrigerants with low GWP (to 2040)
- Establishment of refrigerant-saving technology (to 2040)

2040–2050:
- Efficiency improvement of compressors
- Development of compressors compatible with new refrigerants
- Environment burden reduction through improved compressors with low GWP and natural refrigerants

## Heat Exchanger Technology

- Development of heat exchangers with ultra-low refrigerant amount (to 2030)
- Coefficient Of Performance (COP) improvement and further comfortability by independent ventilation of indoor air circulation and heat exchanger (to 2030)
- Promotion of renewable energy utilization, and control on maximum power consumption by heat storage mechanism (to 2030)

## Frost and Defrost Technology

- Energy-saving by promoting the use of air-source heat pump (to 2030)
- Utilization of air-source heat pump for stable heating (to 2030)
- Improvement of energy-saving performance of air-cooled heat pumps for heating purposes (to 2030)

2030–2050 (Heat Exchanger Technology and Frost and Defrost Technology):
- Dissemination of high efficiency systems by improving heat exchange performance and reducing heat loss due to frost formation and defrosting

## Next Generation Refrigeration and Air-conditioning System Technology

- Realization of a system that can operate with high efficiency from high load to low load (to 2050)
- Optimization of energy balance by networking all heat loads (to 2050)
- Promotion of waste heat utilization, and development of refrigeration, air-conditioning and heat pump equipment that can be operated with lower temperature waste heat (to 2050)
- Simplification and no waste technologies of equipment installation (to 2050)
- Establishment of element and system design, system operation, and performance prediction technologies linked with AI (to 2040)

## Desiccant, Adsorption, Absorption and Chemical Technology

- Development of absorption, adsorption, chemical heat storage material with suitable physical properties (to 2040)
- Elucidation of phenomena in various absorption, adsorption and chemical heat storage technologies and establishment of the theory (to 2040)
- Establishment of system optimization technology for high performance and miniaturization (to 2040)

2040/2050 (Next Generation Refrigeration and Air-conditioning System Technology and Desiccant, Adsorption, Absorption and Chemical Technology):
- Environmental burden reduction by next generation refrigeration and air-conditioning technology (absorption, adsorption, heat storage technology, etc.) that actively utilizes renewable energy
- Widespread use of heat pump systems that enable high temperature heat generation for home and industrial use

## Vision

A carbon neutral era, in which the shift from fossil fuel-derived energy to renewable energy, refrigerant recovery and reuse is being promoted.

Development of products and services that utilize hydrogen, fuel cells and magnetic refrigeration technology to improve the efficiency of hydrogen liquefaction, are considered to be one of the new options. In addition, maximum energy efficiency by spread of Smart Factory, ZEB, ZEH, etc. will be realized by introducing information and communication technology (ICT), using artificial intelligence (AI) and the Internet of Things (IoT).

To achieve this vision, Japan will take a leadership role with its technological capabilities and social infrastructure, for the integration of standards and regulations globally to seamlessly develop products and services with low environmental burdens.

# Themes for Food Technology

## Theme 1: Establishment of food freezing and cold chain technology that complies with hygiene standards

➢ Target year: By 2030

Fundamental issues

- The refrigeration and air-conditioning industry has not been following the world trend complying with relevant hygiene standards on both of the "soft" and "hard" sides.

Solution proposals

- To propose and realize improved food freezing supply chains that comply with GMP, etc. that is the base of various hygiene standards such as European Hygienic Engineering and Design Group (EHEDG) and Hazard Analysis Critical Control Point (HACCP).

## Theme 2: Establishment of quality evaluation model that can comprehensively evaluate from freezing, thawing to consumption

➢ Target year: By 2030

Fundamental issues

- Because the current criteria for frozen food quality are vaguely set, it is difficult to understand what the appropriate evaluation indicators are for food freezing (thawing) technology and cold chain technology.

Solution proposals

- To establish and promote further clarification of frozen food evaluation indicators for systematic food freezing technology and cold chain technology.

## Theme 3: Visualization of the optimum value (optimal energy investment amount) for total engineering in food freezing and cold chains

➢ Target year: By 2030

Fundamental issues

- Although there are qualitative criteria for freezing quickly and maintaining temperature, there are no quantitative criteria for them, and the balance of energy costs is not clarified.

Solution proposals

- To quantify energy costs in the process from production to consumption, and to propose and promote the ideal state of how food freezing technology could be utilized.

## Government supports needed to realize the above-mentioned themes

**○ Guidelines for international standards of GMP, etc. that is the base of EHEDG and HACCP**

- It is desirable to set numerical targets to cope with the international standards and to set a deadline for officially applying them in Japan.
- It is recommended Japanese government to develop a policy to respond to the international standards. Then industry and academia would be able to work toward their goals through collaboration accordingly with that policy.

**○ Guidelines to cope with global warming and climate change issues in relation to economic activities**

- It is hoped that the government will provide clear guidelines on what kind of preparations would be necessary when facing to climate change due to global warming and commodity price fluctuations due to the outbreak of epidemics.

**○ Industry-government-academia collaboration programs**

- It is hoped that the government will set up projects and prepare budgets for the development of domestic and overseas cold chains, evaluation of energy costs, and measures against food loss. In addition, it is expected that the government provides a platform where industry, government and academia can collaborate to think about countermeasures for the issues.

# Themes for Refrigerant Technology (Residential or Commercial Use)

## Theme 1: Search and development of new refrigerants

- Target year: By 2030

Fundamental issues:
- Refrigerant candidates to achieve the final target of the Kigali Amendment to the Montreal Protocol are not specified yet.

Solution proposals
- To develop an innovation ecosystem to accelerate the searching and development of new pure/mixed refrigerants (there is an on-going NEDO projects as of 2021).

## Theme 2: Full utilization of existing refrigerants and expansion of applications due to deregulation

Target year: By 2030

Fundamental issues :
- Natural refrigerants such as propane, $CO_2$ and ammonia have disadvantages in flammability, high pressure and toxicity to restrict usage or degrade system efficiency.

Solution proposals
- To extend the application range of refrigerants with currently limited use such as propane and $CO_2$ by accelerating the development of safety and the improvement of system efficiency.

## Theme 3: Emission reduction by promoting refrigerant recovery

- Target year: By 2030

Fundamental issues:
- It is essential to reduce refrigerant emissions considering the environmental impact in line with the Paris Agreement. The rules and schemes to recover refrigerants are not yet established (recovery rate is 38% in Japan as of 2018).

Solution proposals
- To design, propose and implement new measures considering social schemes and legal structures to facilitate refrigerant recovery.

## Government supports needed to realize the above-mentioned themes

○ **Deregulation for the use of flammable refrigerants such as R32 in ensuring safety**
- It is required to extend the use of flammable refrigerants, such as strongly flammable propane and mildly flammable R32, in maintaining the safety of equipment.
- It is hoped that funding support will be available for additional costs required for safety devices and sensors.

○ **Facilitation of refrigerant recovery to reduce the amount of refrigerants released into the atmosphere**
- It is recommended to add new criteria in the industrial standards for the ease of refrigerant recovery, policy to develop incentive schemes facilitating refrigerant recovery, and to develop a new system to monitor the distribution of refrigerants in the industry.

○ **Encouragement of the reuse of refrigerants to restrain new refrigerant production**
- It is important to reduce the environmental impact by the reuse of regenerated refrigerants with sufficient purity and correct composition ratio for the restrain of virgin refrigerant production.
- It is recommended to have subsidies to encourage the reuse of refrigerants in order to improve the economic competitiveness of regenerated refrigerants compared to virgin refrigerants.

○ **Examination and certification of flammability classification for domestic use of new refrigerants certified by the ASHAE**
- It is suggested to support the establishment of a system to quickly evaluate the classification of new refrigerants, as regulation of refrigerants depends on the classification in the High Pressure Gas Safety Act.
- It is suggested to have research support in order to choose ideal new refrigerant candidates for each product sector through cooperation with foreign organizations related to refrigeration and air-conditioning.

○ **Safety measures for refrigerant leakage, establishment of guidelines, subsidies for installation of ventilation devices and detectors**
- It is suggested to have research support strategically and timely in order to reduce risks at refrigerant leakage, and establish guidelines to secure safety.

○ **Equipment evaluation scheme considering not only the GWP value of refrigerants but also refrigerant charge amount of system during operation**
- Environmental impact by refrigerant leakage is calculated by the carbon dioxide equivalent (GWP x leakage amount). Direct expansion products require additional charge at equipment installation with longer connecting pipes and this additional charge should properly be recorded.
- It is recommended to support the related research tasks in order to improve the measurement accuracy and precision of refrigerant leakage amount for each product sector, and manage the information of refrigerant charge amount during equipment installation.

# Themes for Refrigerant Technology (Industrial Use)

## Theme 1: Search and development of new refrigerants suitable for high-temperature heat pumps

➢ Target year: By 2040

Fundamental issues

- The bottleneck issue for heat pumps having the upper limit of supply temperature is the number short of refrigerant with high critical temperature.

Solution proposals

- To search and develop refrigerants with high critical temperature, high thermodynamic performance, zero ODP, low GWP, sufficient chemical and thermal stability, low toxicity and low flammability.

## Theme 2: Clarification of thermophysical properties and establishment of equation of state

➢ Target year: By 2040

Fundamental issues

- There is no structure to sufficiently evaluate the thermophysical properties of the refrigerants searched and developed.

Solution proposals

- To build a system to carry out quickly from data acquisition to establishment of equation of state for refrigerant thermophysical properties.

## Theme 3: Evaluation of thermodynamic performance and selection of suitable heat pump cycle

➢ Target year: By 2040

Fundamental issues

- Suitable cycle configurations and high efficiency technologies of system differ depending on the thermophysical properties of refrigerant.

Solution proposals

- To establish the evaluation and cycle selection methods that make possible to select a high-efficiency technology suitable for each refrigerant

## Theme 4: Evaluation of compatibility with various materials and lubricant oil

➢ Target year: By 2040

Fundamental challenges

- It is necessary to clarify the refrigerant stability at high-temperature in actual conditions, for example, a state where oxygen, water and metal material are coexistent, the compatibilities of resin material or refrigerant oil.

Solution proposals

- To build a system to share information and tasks regarding refrigerant stability and material compatibility.

## Government supports needed to realize the above-mentioned themes

○ **Statistical database for heat demand and exhaust heat of factories that can be used for heat pump specification**

- Detailed statistical temperature information on heat demand and waste heat in industry field is necessary to specify refrigerants and heat pumps to be developed, therefore, temperature information in increments of twenty is more desirable than that in increments of fifty as statistical database.

○ **Technology development projects**

- It is hoped that the government will support industry-university collaboration for development of refrigerants and lubricant oil.
- It is suggested to support the development of refrigerants and lubricant oil and evaluation of those applicability at the equipment level.
- It is suggested to support the field test of high-temperature heat pumps for applicability verification of refrigerants and lubricant oil.

○ **Economic instruments**

- It is hoped that the government will support the organization making corrections to trade-off of greenhouse gas emissions and system manufacturing cost.

# Themes for Compression Technology

## Theme 1：Efficiency Improvement of compressors

➢ Target year: By 2040

Fundamental issues

- Positive displacement compressors include reciprocating, rotary, screw and scroll compressions. The technical maturity of these compressors is extremely high, and many structural improvements have been done so far. On the other hand, in order to improve the efficiency of compressors, it is crucial to pursue not only structural improvement but also improvement of machining and assembly accuracy.

Solution proposals

- To improve the accuracy, quality and productivity of machining and the assembly by utilizing digitization and automation of plant and equipment utilizing AI and IoT.

## Theme 2：Adaptation to various refrigerants with low GWP

➢ Target year: By 2040

Fundamental issues

- There is a wide variety of low GWP refrigerants for each country with different regulations, different regions including tropical area and cold area, and different products including refrigerator, air conditioner, freezer, etc. Compressors are required to have equipment design that enables stable operation for various refrigerants. In response to such demand, there are many elemental technology fields required for compressor development. And many certification processes exist due to changes in compressor parts suitable for low GWP refrigerants, and its development lead time is too long.

Solution proposals

- It is expected that compressor components such as refrigeration oils, materials of parts, motors and pumps will become more modular to efficiently meet a wide variety of needs. The development lead time will be shortened by actively introducing 1D-CAE that systematically models complex related factors in the entire system and by strengthening the design in the upstream process of development.

## Theme 3：Establishment of refrigerant-saving technology

➢ Target year: By 2040

Fundamental issues

- It is required to reduce the volume of compression chamber because reducing the amount of refrigerants charged when using flammable refrigerant leads to reduction of risk and prevention of global warming. However, cooling and heating capacities tend to decline due to the performance characteristic of many low GWP refrigerants. It becomes necessary to increase the volume of compression stroke and the pump size. This makes it difficult to reduce the volume of the compression chamber.

Solution proposals

- High-side pressure chamber type with small discharge pulsation and stable oil supply is mainstream in the Japanese air-conditioning industry. On the other hand, low-side pressure chamber type that uses the flammable refrigerant R600a is mainstream for household refrigerators in Japan. It is expected that low-side pressure chamber will be one of the means to reduce the volume of the accumulator attached to the compressor and reduce the amount of refrigerant charged.

## Government supports needed to realize the above-mentioned themes

○ **Subsidy system to encourage the introduction of energy-saving products**

- It is recommended to support building the foundation that encourages innovation and research, which are the basis of energy-saving technology for the refrigeration and air-conditioning industry. For example, it is expected to develop open innovation framework through industry-university collaboration of university-launched ventures and Small and Medium-sized Enterprises(SMEs) with advanced technology.

○ **Development of telecommunication infrastructure, including the development and dissemination of 5G/6G infrastructure**

- Researches of refrigeration and air-conditioning linked to information and communication technologies like AI and IoT are progressing such as smart factories and digital twin of production lines, smart buildings, smart grids and automated demand responses. Since the refrigeration and air-conditioning equipment has high affinity particularly to the connected other systems, it is expected that the government will support the activities relating to consortium that includes other academic societies and industrial companies.

○ **Subsidies or tax incentives for capital investment by manufacturers**

- It is expected that the government will support the research and development of high-mix low volume production such as 3D printers and manufacturing equipment that can meet a wide variety of demands.

○ **Subsidy of fund for R&D in industry-academia-government joint project**

- To promote the introduction of renewable energy and realize a hydrogen-based society, it is expected that the government will support the research on efficiency improvement of future technologies utilized in new society such as the operation by electricity from storage batteries, solar power system, etc.

○ **Regulations and standards for slightly flammable, highly flammable refrigerants and toxic refrigerants**

- It is suggested that the government will support open conferences on the topic of safety of refrigerants beyond the boundaries of each academy.
- It is recommended that the government will support research that promotes the introduction of refrigerant-saving products to the market.

○ **Tax incentives and subsidies for development costs and capital investment for the use of refrigerants with low GWP**

- Safety measures are indispensable for research and development of high-pressure gas such as $CO_2$ and highly flammable gas such as propane. The entry barrier of this research is high. It is recommended to support basic research based on the cooperation of universities and research institutes regarding these refrigerants to cope with this entry barrier.

# Themes for Heat Exchanger Technology

## Theme１：Development of heat exchangers with ultra-low refrigerant amount

➢ Target year: By 2030

Fundamental issues

- The reason why refrigerant amount of the existing heat exchangers tends to be large is because of the followings: 1) Refrigerant distributor is large, 2) Heat flux is small on the refrigerant side, and 3) Refrigerant flow path is long.

Solution proposals

- To develop a small refrigerant distributor and establish optimization technology of "flow path area x flow path length x number of paths" in consideration of fin arrangement on the air side. The development of heat exchangers with ultra-low refrigerant amount needs to proceed through industry-academia collaboration. It is also desirable to establish a refrigerant path optimization method by AI technology.

## Theme２：Coefficient Of Performance (COP) improvement and further comfortability by independent ventilation of indoor air circulation and heat exchanger

➢ Target year: By 2030

Fundamental issues

- The existing indoor unit fans usually have insufficient indoor air circulation, and the difference between the temperature around indoor unit heat exchanger and the indoor air average temperature is large, which is disadvantageous in terms of comfort and COP.

Solution proposals

- It is necessary to improve comfort and COP by independently controlling the ventilation of heat exchanger and the indoor air circulation. Providing a dedicated fan for the heat exchanger allows greater flexibility in design and improves the performance of the heat exchanger. It is necessary to promote industry-academia collaboration along with sharing indicators and goals related to comfort.

## Theme３：Promotion of renewable energy utilization, and control on maximum power consumption by heat storage mechanism

➢ Target year: By 2030

Fundamental issues

- The reason why heat storage mechanism has not been yet realized, in addition to the fact that an effective method was not established, is that there are negative factors such as increases in cost, the amount of refrigerant charged, and intensified cost competition with electricity storage.

Solution proposals

- In order to promote the use of renewable energy and control the maximum power consumption by heat storage, it is necessary to have a system that gives incentives for such products, and it is desired to promote it through industry-academia-government collaboration.

## Government support needed to realize the above-mentioned themes

○ **Certification and purchase subsidy systems**

- A certification and purchase subsidy system should be established for products in which “the amount of refrigerant charged x the value of GWP of the refrigerant” with respect to air-conditioning capacity of the heat pump system is small, or tax should be levied on “the amount of refrigerant charged x the value of GWP of the refrigerant.”
- A certification system should be established for products that are highly comfortable and energy-saving, and have functions that are effective in preventing heat stroke. The certificated product must have a higher COP than conventional products, sufficient indoor air circulation capacity, and a function to detect humans and automatically start operation in order to prevent heat stroke.
- A certification and purchase subsidy system should be established for products that can utilize a surplus power generation of renewable energy and contribute to peak shaving by heat storage. The product needs to have a function to acquire information on the amount of renewable energy and the power consumption occur in the region.

# Themes for Frost and Defrost Technologies

## Theme 1 : Energy-saving by promoting the use of air-source heat pump

➢ Target year: By 2030

Fundamental issues

- Air-source heat pump absorbs thermal energy from outside air in it's outdoor unit. And especially in cold weather, the outdoor unit of air-source heat pump gets easily frosted by achieving the air dew point. When the outdoor unit coil frost, it needs to be defrosted by reversing refrigeration cycle. In the defrost cycle, Indoor temperature drops and air temperature control functionality becomes low by defrosting. The longer defrosting time, the worse air temperature control functionality is, and the issue is how to shorten defrosting time.

Solution proposals

- To propose to the government to develop a subsidy system for technology development to improve the heating performance of air-source heat pump.

## Theme 2 : Utilization of air-source heat pump for stable heating

➢ Target year: By 2030

Fundamental issues

- Air-source heat pump absorbs thermal energy from outside air in it's outdoor unit. And especially in cold weather, the outdoor unit of air-source heat pump gets easily frosted by achieving the air dew point. When the outdoor unit coil frost, it needs to be defrosted by reversing refrigeration cycle. In the defrost cycle, Indoor temperature drops and air temperature control functionality becomes low by defrosting. The longer defrosting time, the worse air temperature control functionality is, and the issue is how to shorten defrosting time.

Solution proposals

- To develop new refrigerant control for defrosting.
- To examine the different defrosting methods.
- To Development of heat exchanger hard to get frosted.
- To improve predictive technology for frost.

## Theme 3 : Improvement of energy-saving performance of heat pumps for heating

➢ Target year: By 2030

Fundamental issues

- Heat pumps consume additional energy to raise the room temperature and air-conditioning circulation water temperature decreased by defrost operation.

Solution proposals

- To develop a refrigerant control technology to match with the air condition of outdoor unit, for example, as monitoring dew point of outdoor unit outlet air.
- To develop defrosting methods except reverse cycle defrosting operation.
- To develop heat exchangers that are not easily to get frosted.

## Government supports needed to realize above-mentioned themes

**〇 Further subsidies to increase the usage rate of air-source heat pump**

- It is suggested that the government will promote energy saving of air-source heat pump.
- It is recommended to promote further subsidies to increase the usage rate of air-source heat pump.
- It is hoped to realize active introduction in government buildings.

**〇 Data analysis, disclosure, etc. for the air-source heat pump used in the government buildings and its effects on carbon dioxide emission reduction**

- It is suggested to support the data analysis for post-introduction in government buildings.
- It is recommended to manage and disclose the data organized for the effect of heat pumps on $CO_2$ reduction by the Ministry of the Environment of Japan.
- It is requested to manage and disclose the data organized for foreign air-source heat pump usage areas and spread status data.

**〇 Subsidy for further technological innovation particularly for universities**

- It is hoped that the government will support research funding available to universities and research institutes for accelerating technological innovation.

**〇 Formulation of framework for the target value of heat pump penetration rate and other technologies for carbon dioxide emission reduction**

- It is necessary to determine the target levels of heat pump penetration rates and of other technologies for $CO_2$ emission reduction.

# Themes for Next-generation Refrigeration and Air-conditioning System Technology

**Theme 1: Realization of a system that can operate with high efficiency from high load to low load**

- Target year: By 2050

Fundamental issues
- The reason why high efficiency at high load and low load cannot be achieved at the same time is that device performance deteriorates at low load when designed for high load (overcompression, deterioration of motor efficiency, and decrease in refrigerant flow velocity for heat exchanger, etc.). During low-load operation, the ratio of power used for heat transfer such as blowing air is large in the total power consumption. Hence, the heat transfer power cannot be reduced, and the performance deterioration in intermittent operation is also a cause for it.

Solution proposals
- To develop an overcompression prevention mechanism and a mechanism through industry-university collaboration. It should always be operated at the maximum rotation speed on the motor characteristics including transmission mechanism and variable capacity.
- To develop the materials and elements of refrigeration and air-conditioning system through industry-university collaboration.
- It is recommended to develop high-efficiency control technology for system and heat exchanger having the change of the cross-sectional area in refrigerant flow path considering heat transfer tube widening or contraction and variable number of paths according to the load.
- To develop technology for heat transportation by natural circulation or radiation through industry-university collaboration.
- To develop separate installation and linkage control system of small-capacity units, bringing the load and heat source closer.
- To demonstrate the developed technologies through industry-university collaboration.

**Theme 2: Optimization of energy balance by networking all heat loads**

- Target year: By 2050

Fundamental issues
- There is a lack of system technology for grasping and integrating the heat load generated in an extensive area over individual locations, and also for heat transportation over a wide area when a load gap occurs. Furthermore, It is short of technology for high density thermal energy storage when a heat load gap occurs over time.

Solution proposals
- To develop a system that grasps and distributes all individual loads through industry-academia-government collaboration.
- To develop technology to convert surplus waste heat with low temperature into transportable energy (e.g., heat to electricity conversion).
- To pursue material and device developments through industry-academia collaboration.
- To develop a mechanism that enables to share the costs incurred with respect to the distributed heat amount.
- It is suggested to develop heat storage materials that can store heat at high density.

**Theme 3: Promotion of waste heat utilization, and development of refrigeration, air-conditioning and heat pump equipment that can be operated with lower temperature waste heat**

- Target year: By 2050

Fundamental issues
- Waste heat of about 80 Degree Celsius is largely available, and waste heat utilization with lower temperature is required to promote further utilization of waste heat. Currently, the range of waste heat temperature that can be used is limited, the cooling capacity per unit volume is low, and the system becomes large when the cooling capacity is high. Therefore, installation location tends to be limited.

Solution proposals
- To innovate further the absorption and adsorption system used as a conventional waste heat recovery device and to develop a high-efficiency heat pump system technology that uses lower temperature waste heat as a heat source.

**Theme 4: Simplification and no waste technologies of equipment installation**

- Target year: By 2050

Fundamental issues
- Since high-pressure refrigerants such as R410A and R32 are used, installation work is usually carried out using metal (copper), and specific skills are also required to bend, cut and braze pipes that cope with corrosion resistance and maintaining durability. It also takes time to vacuum refrigeration cycle equipment.

Solution proposals
- To develop a low-pressure refrigerant similar to R134a and develop a technology to reduce pressure loss when using low-pressure refrigerant, and to develop low-cost materials with high corrosion resistance, durability, flexibility and utility.
- To develop technologies that shortens or eliminates the vacuum time of refrigeration cycle equipment.
- To develop technologies that automatically removes and adsorbs air during operation without evacuating through industry and academia collaboration.

**Theme 5: Establishment of element and system design, system operation, and performance prediction technologies linked with AI**

- Target year: By 2040

Fundamental issues
- Current applications of AI technology in refrigeration and air-conditioning field is still in the early stage. The challenges are to develop applications and evaluation methods to further expand the applied technologies, understanding the physical implications of results simulated using AI technology.

Solution proposals
- To develop appropriate algorithms on AI technology and searching of physical phenomena by AI technology. These developments can link with the optimal design and operation of element and system to perform the highest capabilities.

Government support needed to realize the above-mentioned themes

○ **Industry-academia-government collaboration programs**
- It is suggested that the government will support further industry-academia-government collaboration programs for new mechanism development, new material development, new refrigerant development, new construction method development, new device development, IT network construction, and thermal circuit construction.
- It is expected that the government will formulate a new technology strategy that can respond to and cope with differences in standards between Japan and overseas.

○ **Development of a performance display method to cope with improved heat insulation**
- Since it is expected that the building will be even more highly insulated in the future, it is necessary to develop a performance display method according to the actual situation, and to establish a new construction method, standards for heat consumption and supply, and legislation.

○ **Funding such as loan system for system development and new business creation**
- Loans related to system development and loans to new businesses are required.

○ **Deregulation for system installation**
- It is expected that relevant necessary qualifications will be relaxed for simplification of installation in the system.

# Themes for Desiccant, Adsorption, Absorption and Chemical Technologies

## Theme １：Development of absorption, adsorption, chemical heat storage materials with suitable physical properties

- Target year: By 2040

Fundamental issues

- Superior material characteristics are required, considering durability, corrosiveness, safety, absorption capacity, adsorption capacity, heat storage capacity, etc., compared with the characteristics of conventional absorption, adsorption and chemical heat storage materials.

Solution proposals

- To develop superior absorption, adsorption and chemical heat storage materials in cooperation with the chemical engineering community based on elucidation of physical phenomena of relevant materials with mathematical approaches.

## Theme ２：Elucidation of phenomena in various absorption, adsorption and chemical heat storage technologies and establishment of the theory

- Target year: By 2040

Fundamental issues

- There is a lack of understanding toward fundamental physical phenomena for absorption, adsorption and chemical heat storage materials newly introduced. Reliable operation and evaluation of system performance and characteristics are required from a viewpoint of practical use considering abstruse physical phenomena.

Solution proposals

- It is recommended universities and research institutes to theoretically investigate absorption, adsorption and chemical heat storage phenomena, building up those technologies as academic discipline, and establishing technologies adaptable to industry as refrigeration and air-conditioning technologies.

## Theme ３：Establishment of system optimization technology for high performance and miniaturization

- Target year: By 2040

Fundamental issues

- System operation has been generalized by combining absorption, adsorption and chemical heat storage systems with other types of system due to heat driving. Hence, superior control operation technologies are required as entire system that is very large and complicated facilities.

Solution proposals

- To construct control systems capable of high efficiency operation of hybrid system.
- To develop analysis technologies considering various operation patterns (Steady and unsteady state/intermittent operation, etc.).

## Government support needed from the above-mentioned themes

**○ Standard and operation deregulation**

- Absorption, adsorption and chemical heat storage technologies in Japan are considered as the world-leading level including management skills. There are lots of natural refrigerants as working fluids in each technology, and It is expected that these technologies utilizing natural refrigerants further will get a lot of attention after technological advancement toward low GWP refrigerants. It is suggested that deregulation should be implemented to support the development of those technologies including food, beverage, biogas, coalbed methane, cogeneration, geothermal heat, solar, etc.

**○ Reinforcement of incentives**

- To accomplish the technological innovation and the dissemination of those equipment, it needs to be strengthened by incentive programs having closely cooperative relation between the public and private sectors. Especially, giving incentives for developing waste heat recovery technologies would be useful to foster further absorption, adsorption and chemical heat storage technologies because these technologies tend to be used as hybrid system.

**○ Project vitalization of public and private sector**

- It is expected that equipment by absorption and adsorption and heat storage equipment by chemical material will link with the supply chain technology in future, and these challenges are not only for Japan but also for overseas. Taking these facts into account, government supports for public-private research projects are required for absorption, adsorption and heat storage equipment that cover both domestic and overseas markets and industries.

**○ International consortium vitalization supported from government**

- Support of international consortium vitalization, etc. are expected to accelerate further technological innovation by looking at technological challenges from a global perspective and improving technological capability and communicative activity.

# 5. Future Plan

# Future Plan

## Exchanging information and opinions with relevant stakeholders for improvement

- Based on the developed roadmap, we plan to proceed with exchanging information and opinions with relevant stakeholders from government, academia and industry, to improve strategic alignment and consistency with the 2050 vision, technology development themes and directions.

## Internationalization of JSRAE

- We plan to establish a new committee group to explore and examine the potential role of JSRAE providing a platform for exchanging opinions and having discussions globally in the field of refrigeration and air-conditioning technology including understanding and future prediction of values for digital transformation, nanotechnology and resource utilization.

## Development of implementation roadmaps to contribute to 2050 vision

- The aims of developing the 2050 roadmap were to build a shared vision for the 2050 goal of carbon neutrality, to propose technological contributions to the vision, and then to suggest technology development themes and directions to facilitate further cooperation between industry, academia and government for its realization. As future activities, we plan to develop implementation roadmaps as specific routes to contribute to realize the 2050 vision.

# List of Committee Members

Roadmap Development：JSRAE Working Group Members

Observers：JSRAE Policy Board Committee

Advisor：Dr Yuta Hirose
(Advanced Institute of Industrial Technology and University of Cambridge)

Japan Society of Refrigerating and Air-Conditioning Engineers (JSRAE)