Heat Pumps

Long-Awaited Way out of Global Warming

Heat Pump & Thermal Storage Technology Center of Japan

Introduction

Can you believe it? Such realities are already within our reach : The use of CO_2-emitting ‘fire’ has become a thing of the past.

Here comes a new era in which we can use a clean, renewable and inexhaustible energy source of which we haven’t ever been aware. This is not at all fantasy. In fact, the dream technology that meets all these challenges is in our hands already.

Problems associated with global warming and energy security are the issues that mankind in the 21st century must overcome. The key to resolving these problems lies in realizing dramatic improvements in energy efficiency and decarbonization of energies. A technology that can accomplish both these tasks simultaneously is the“ heat pump”.

As a resource-scarce nation, Japan has waged a government-orchestrated campaign to promote energy efficiency, drawing lessons from the Oil Crisis in the 1970s that triggered the unrest of resource imports. These efforts helped the nation to achieve the highest energy conservation standards in the world. And it was the heat pump technology that made this feat possible as a major pillar of energy-saving technology in the residential and business sectors.

Most households in Japan are equipped with heat pump heating and cooling equipment. Under the government’s “Top Runner Regulations”, a unique program even by global standards, home appliance retailers dispense at reasonable prices air-conditioners that vie for the world’s highest level performance. Highly efficient heat pumps are also employed in large-scale district heating and cooling (DHC) services.

Moreover, Japan developed, for the first time in the world, a CO_2 refrigerant heat pump water heater, an equipment that takes advantage of “heat in the air” to supply hot water. As such, Japan is one of the most advanced countries in heat pump technologies.

It is our earnest hope that more and more people tackling global warming would become aware of the “heat pump technology.” The astonishing reality is that the heat pump, which supplies heat with much less energy consumption, has an enormous impact on energy conservation and CO_2 reduction. We wish to make a contribution globally through the dissemination of this innovative technology to save our planet that is on the verge of crisis.

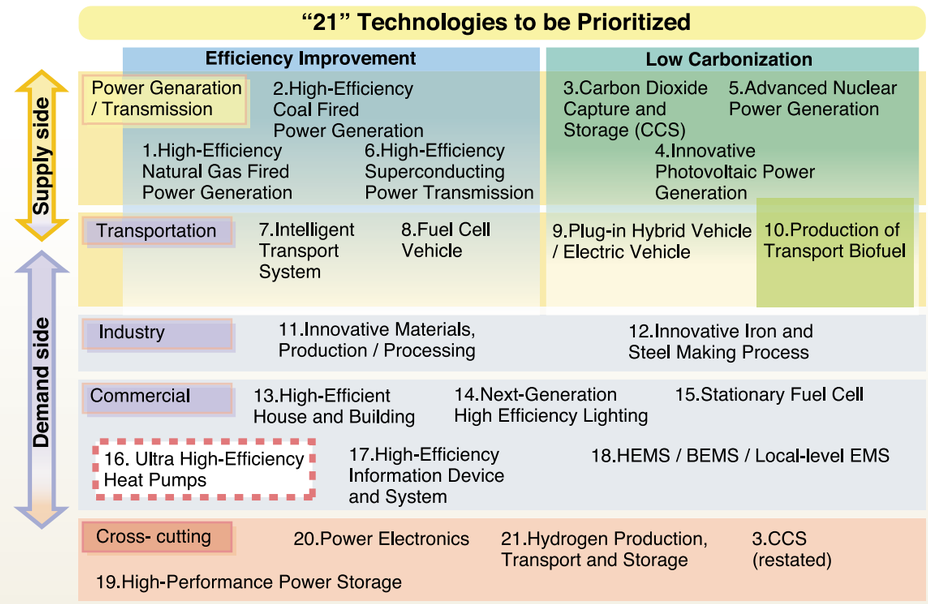
Current Situation

Today, as problems associated with global warming increasingly threaten our environment, the time has come for heat pumps, with their rapid technological innovation, to show their true ability on the international scene as the trump card in the measures against global warming.

Based on a concept devised by Sadi Carnot and developed by Lord Kelvin and others in the 1800s in Europe, this thermal utilization technology has a long history for use in refrigerators and for cooling.

In contrast to cutting-edge technologies under development that tend to attract wide public attention and expectations, the public has shown little interest in the fundamental mechanism of heat pump, which is a mature conventional technology. For all these reasons, the truth about heat pumps – that widespread dissemination of the heat pump technology holds huge and realistic potential for resolving both energy and environmental issues confronting humans – has not been fully understood in spite of its monumental significance.

Japan's 21 Innovative Technologies for GHG Reduction

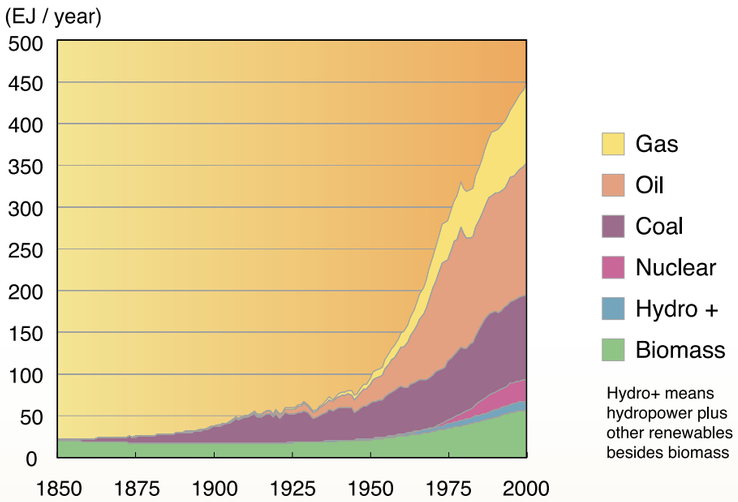


(source : Cool Earth-Innovative Energy Technology Program 2008)

Need for Combustion-free Systems: A Conversion from Fossil Fuel-dependent Culture

In the commercial sector that includes residences and office buildings, the bulk of the energy has been consumed for heating, hot water supply and other purposes to sustain living. This energy comes primarily from "combustion" systems that utilize thermal energy generated by burning fossil fuels.

World primary energy supply 1850-2000



Fossil fuels supplied 80% of the world's energy in 2000.

The 4th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) has concluded that global warming, which today calls for urgent response, is "very likely" to have been caused by an increase in the atmospheric concentration of carbon dioxide (CO_2) that accompanies mass consumption of fossil fuels as a result of human activity.

In order to resolve global warming issues, break away from the constraints posed by fossil energy resources and realize environmental preservation along with sustainable development of our economy and society, we need to build a "low-carbon society" that accomplishes a substantial reduction of CO_2 and other GHG emissions and stabilizes the atmospheric concentration of GHGs at levels that would not adversely impact the climate.

In this regard, the heat pump is the key technology that would enable energy suppliers and consumers to make an active choice to join the movement to halt global warming.

Outstanding Features of Heat Pump: A Highly Efficient Heat Transport Mechanism

Heat pumps have two outstanding features.

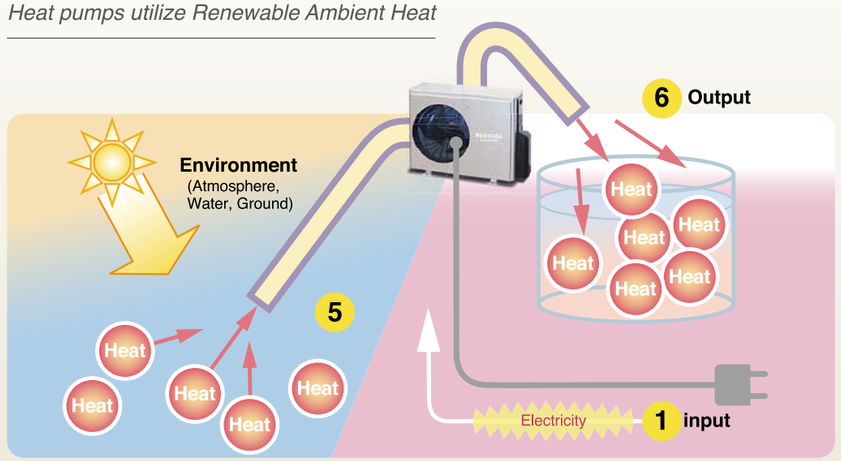
First, a heat pump moves thermal energy between outdoors and indoors instead of "generating" thermal energy from scratch by combustion. The heat pump, based on a simple heat transport mechanism that applies basic principles of thermodynamics, is already widely used in refrigerators and for cooling and other purposes.

Second, theoretically speaking, the energy consumption efficiency of a heat pump system is much higher than that of a combustion-based system by several times to more than tenfold. The amount of thermal energy transported is much larger than the inputted energy (normally electric power) consumed to power thermal transport. This means that collecting ambient heat by a heat pump after converting fossil fuels into electricity is a more efficient – resource-saving and CO_2 reducing – means of obtaining heat than burning fossil fuels directly.

In the past, attention on the heat pump, being an essential technology for cooling purposes, has been focused primarily on the first feature as a heat transport mechanism. Although its theoretically high efficiency has been known, little attention has been paid to the energy-saving properties, the second feature, of this technology partly because the technology was in the developing stage and also because fossil fuels for competing combustion equipment could be obtained at low cost.

However, amid major transformations in energy, environment and other social conditions in the past decade or so, the appearance of many kinds of heat pump equipment with higher energy consumption efficiency on the market has reinvigorated interest in the energy-saving properties of heat pumps.

Heat pumps utilize Renewable Ambient Heat



Rapid Technological Progress

Rapid technological innovation in the heat pump technology has been fueled by two major factors: continuous improvement, or “kaizen”, at the production site toward greater energy conservation and expectations for a combustion-free technology that would help combat global warming.

A monumental breakthrough was achieved with “Eco Cute,” a CO_2 refrigerant heat pump water heater, which was developed in 2001 in Japan as the first such product in the world. Eco Cute opened up new possibilities for the application of heat pumps in high temperature hot water supply systems, an accomplishment that had been difficult with CFC-based refrigerants, while its high efficiency led to substantial improvements in both energy conservation and CO_2 reductions. In 2009, a cumulative total of more than two million units of Eco Cute have come into wide use in Japan with strong support of the government as measures against global warming.

The Japanese government has introduced a scheme named, the “Top Runner Regulations” in an effort to encourage continuous improvement in the energy-saving performance of various home electric appliances. This one-of-a-kind program in the world has served to double the energy consumption efficiency of air-conditioners for residential use in just ten years and has proved the status of heat pumps as being far superior to combustion-type heaters in terms of energy-saving and CO_2-reducing performance.

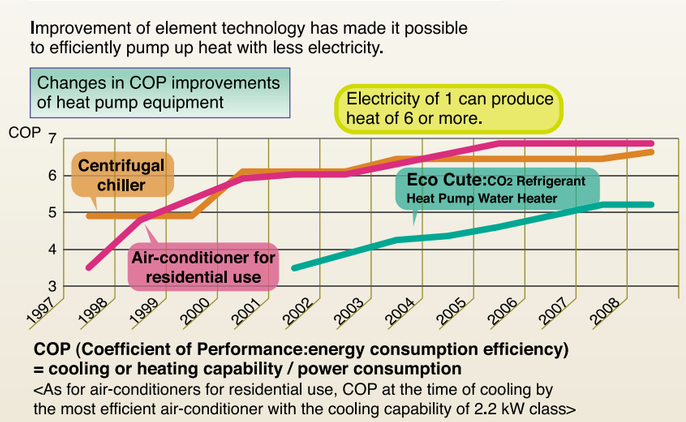
The IPCC shows in its Fourth Assessment Report that the heat pump air-conditioners in Japan are much more efficient than those in North America and Europe; the range of nominal efficiency ratio (COP: Coefficient of Performance) of Japan is from 4.5 to 6.2, while of the latter is from 2.2 to 3.8 (cooling COP of 2.8 kW air-conditioner for residential use).

Globally, high-efficiency centrifugal chillers, developed in the U.S. with the application of heat pump technology, are widely used for cooling office buildings and district cooling. Also, in recent years, further advances in the energy conservation performance have been achieved with the commercialization of centrifugal chillers that allow variable speed operation with inverter control.

In Europe and North America, besides the traditionally developed geothermal heat pumps utilizing heat in the ground, the air-source heat pumps that supply hot water for space heating even under severe cold climate are rapidly increasing.

Furthermore, newly invented efficient heat pumps are now replacing steam boilers to supply heat in the industrial sector.

Heat Pumps of Japan Are Remarkably Increasing Their Efficiency in Recent Years



COP (Coefficient of Performance:energy consumption efficiency) = cooling or heating capability / power consumption
<As for air-conditioners for residential use, COP at the time of cooling by the most efficient air-conditioner with the cooling capability of 2.2 kW class>

Potential of CO_2 Reduction

Expectations for heat pumps to reduce CO_2 emissions are growing higher in every country.

In the Japanese commercial sector for residential and business uses, energy consumption has been constantly expanding over these years. In this sector, heating and hot water supply account for nearly half of the energy consumed, which is one of the main contributors to the CO_2 increase. Moreover, about 90% of hot water supply, heating and other heat-based demands are met by the heat generated by burning CO_2-emitting fossil fuels. Also, absorption-type refrigerators that burn fossil fuels are commonly used in the business sector for cooling, mainly in large-scale facilities.

By replacing fossil fuel-based direct combustion systems prevalent today with heat pump equipment, which drastically improves energy utilization efficiency with the use of “ambient heat” to meet such demands for cooling and heating, primary energy consumption and CO_2 emissions can be reduced substantially without changing the amount of thermal energy available to users.

An estimation was made on the basis of current energy demand figures in Japan to gauge the impact of the maximum possible introduction of heat pumps on CO_2 emission reductions. The projected CO_2 emissions reductions totaled 130 million tons per year, equivalent to about 10% of Japan’s total CO_2 emissions at present.

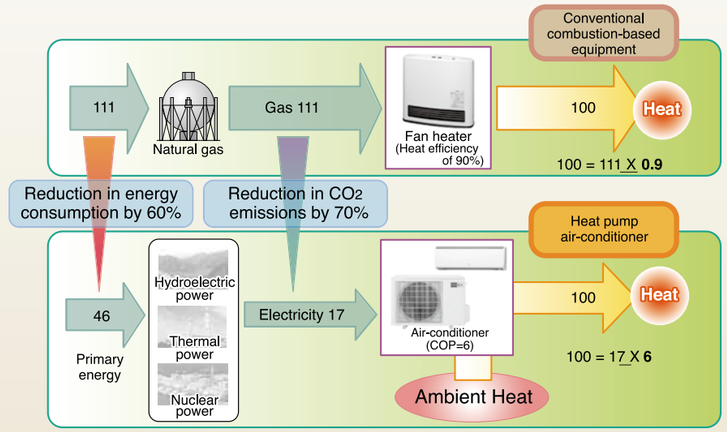
A simulation by the IEA Heat Pump Center estimates that more widespread use of heat pumps would cut the world’s CO_2 emissions by about 8% or 1.8 billion tons.

Furthermore the advantage of CO_2 reduction can be quite easily realized by heat pump equipment that is already available on the commercial market. Therefore, we should draw more attention to the highly effective and realistic measures of heat pumps.

In his report titled, “Technology for a Low Carbon Future,” the former British Prime Minister Tony Blair evaluates such technologies like heat pumps as “already proven, available now,” and suggests that policies are needed to make them widely known.

IPCC Chairman, Dr. Rajendra Pachauri also said in his lecture in 2008, “We don’t have to wait for the technological breakthrough because we have already had the existing and available technologies necessary to prevent global warming, including heat pumps. The key is how we widely spread such existing technologies.”

Use of Ambient Heat by Heat Pumps Is the Key to Energy Conservation and Reduction in CO_2 Emissions



Note: Carbon Intensity: Gas: 0.0138kg-C/MJ, Electricity: 0.37kg-CO2/kWh

Significance of Dissemination that Extends Beyond CO_2 Reduction

As we have seen, the replacement of fossil fuel consumption with renewable energy, the "ambient heat" amassed by heat pumps, carries great significance in various ways. Its CO_2 reduction performance would not only have a huge impact on controlling global warming, but would also significantly cut back on the amount of resource imports and contribute to energy security, and promote the utilization of renewable energy that takes advantage of clean and inexhaustible heat in the air prevailing in the natural world.

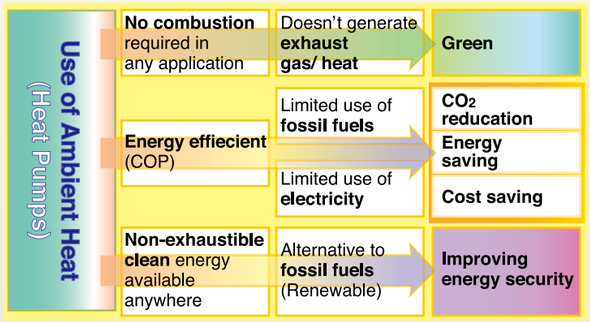
In 2008, the Japanese government set up the "Cool Earth Energy Innovative Technology Plan" in order to develop and deploy the technologies necessary to halve GHG emissions by 2050. This promotional plan selected heat pumps as one of the 21 innovative technologies to be intensively addressed, and set the development target to halve the cost and double the efficiency of heat pumps by 2050.

Japan, a nation scarce in natural resources, is not the only country that carries out measures to disseminate heat pumps. In an effort for doing without oil and without global warming, steps to promote the use of heat pumps are actively pursued in Europe and the U.S. They promote the thermal utilization of renewable energy and also mitigation of the energy supply-demand situation that has tightened further in response to the growth in global energy demand that is expected to continue into the future.

The EU adopted a policy package to tackle climate change in 2008, including the target of 20% reduction of GHG emissions by 2020. In the Directive on the promotions of the use of energy from renewable sources(RES-Directive) issued by the EU in 2008, the energy captured by heat pumps for heating and cooling(aerothermal, geothermal and hydrothermal energy), shall be accounted for renewable energy. Under such directives, each member country sets up its action plan to promote renewable energies, including using heat pumps.

In "Energy Technology Perspectives (ETP) 2008,"the IEA's energy scenario responding to the G8 call to achieve 50% CO_2 reduction by 2050, heat pumps were selected as one of the 17 key technologies to attain this target. The detailed roadmap needs to be examined for spreading these technologies around the world.

Implications of Heat Pumps



Pathway to a low-carbon society: synergy of de-carbonization & energy efficiency

To stabilize the concentration of CO_2 in the atmosphere, a major cause of global warming, it is necessary to reduce the world's total CO_2 emissions by half in the medium term. The follwing "Kaya identity," which analyzes the factors of CO_2 emissions, provides an idea of an effective measures to take.

CO_2 Emissions = GDP × Energy Intensity (energy consumption per GDP)
× CO_2 Intensity (CO_2 emissions per energy consumption)

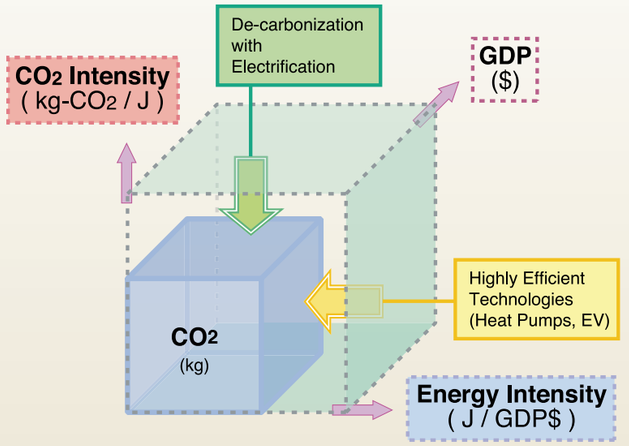
The implication of applying heat pumps, in terms of CO_2 reduction, is that drastic improvement of energy efficiency is obtained by replacing inefficient fossil fuel combustion systems, while maintaining the same amount of heat demand. In other words, decreased energy intensity contributes to substantial emissions reduction without affecting human activities that are represented by GDP.

Thus, end-use energy efficiency is the fastest, cleanest and cheapest energy resource currently available and also is the most effective near-term technological option to reduce GHG emissions across the world.

Moreover, the synergy effect of improving efficiency at the demand side and decreasing CO_2 intensity at the supply side (de-carbonization of energy) is easily obtained if we apply heat pumps. The CO_2 intensity of electricity which drives heat pumps is expected to decrease by the increasing use of renewable and nuclear energy.

Eurelectric, the federation of electric utilities in Europe, showed this concept in its scenario titled "The Role of Electricity" toward creating a low-carbon society. Highly efficient appliances, especially heat pumps and plug-in hybrid electric vehicles to replace combustion, are suggested to be used with low carbon electricity to maximize CO_2 reduction.

Synergy of Electrification & Highly Effiecient Technologies



Electrification, which brings significant synergy of low-carbon energy supply and energy-efficient electro technologies, shall be a key element to building a sustainable low-carbon society.

Japan's Position

With the intensification of measures to tackle global warming in recent years, the reputation of the heat pump technology has come to be established as a realistic and highly effective means for energy conservation and CO_2 reduction. This, in turn, further raised expectations on heat pumps as a tool for resolving both energy and environmental problems at the same time.

Also, the successful development of various types of heat pumps in Japan may be attributed to its climatic conditions – warmer and more humid than in Europe or the U.S. – that are fit for heat pumps. By installing a heat pump air-conditioner, heating and cooling needs can be met without having to install separate units, which means small energy consumption and less energy costs. The same applies to heat pump hot water supply.

However, due to their high initial costs in comparison to simple combustion-based systems, the dissemination of heat pump systems has been far from adequate.

At present, the Japanese government is launching a campaign to promote the use of heat pump units, rating them highly in the Kyoto Protocol Target Achievement Plan, New National Energy Strategy, reports by environment and energy-related government councils and other programs. Also, the government hopes to make a positive contribution by disseminating globally Japan's energy conservation technology, which ranks among the top in the world, toward building a "low-carbon society" for a better global environment.

Conclusion

Heat pumps use the power of technology to recycle the heat found in the air and ground – a recyclable, clean and inexhaustible supply with the gifts of the sun. A solar energy recycling society, which recycles of the heat in the air, heat in the ground, heat in the lake water and heat in the river water, is the ultimate sustainable society.

It is our earnest hope that the world will make common efforts to allow all businesses and citizens to utilize the heat pump technology, and, with the total outcomes thereof, to create a sustainable low-carbon society that is free from dependence on the use of fossil fuels.

Let's Save the Earth with Heat Pumps!

Now, our life built upon the heavy use of limited and precious natural resources such as gas and oil is reaching a turning point.

For human beings to survive through the 21st century, technology that makes use of the inexhaustible ambient heat for air-conditioning and for hot water supply, greatly reducing CO_2 emissions, is essential.

Can you believe that such technology already exists and has been widely used? That is "Heat Pump" technology!

By spreading the use of Heat Pump technology, a reduction of 130 million tons in annual CO_2 emissions can be expected in Japan. That is equivalent to 10% of Japan's annual CO_2 emissions.

As the leading country of this highly efficient, revolutionary technology for energy conservation and CO_2 emission reduction, we entreat the world to widely utilize Heat Pumps.

Together we can save the Earth on the brink of a global warming crisis.

Hiroshi Komiyama *President, the University of Tokyo (Chairman, Heat Pump & Thermal Storage Technology Center of Japan, since July 2009*

Kiyoshi Kurokawa *Special Advisor to the Cabinet and former President of Science Council of Japan*

Hiroshi Kato *Chairman, Heat Pump & Thermal Storage Technology Center of Japan (until June 2009), Professor emeritus, Keio University*

Hiroshi Kato **Kiyoshi Kurokawa** **Hiroshi Komiyama**

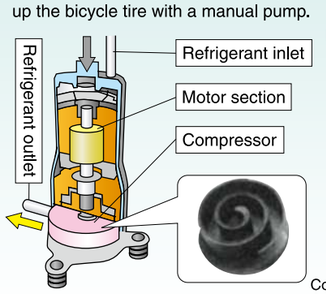
This proposal was originally released in the Wall Street Journal (USA, Europe and Asia edition) in May 2008. (Note that the job titles of the individuals may have changed since publication.)

Mechanisms of CO_2 Refrigerant Heat Pump Water Heater for Residential Use (Eco Cute)

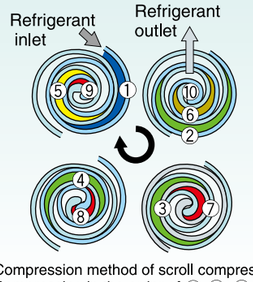
Electricity of 1 takes in 2-4 of thermal energy and gets 3-5 of hot water supply (thermal) energy.

① Compressor

Compressor compresses refrigerant (CO_2) to warm it up.
(For example, from about 10℃ to 130℃)
→ It's the same principle of pump tube getting warmer, when you pump up the bicycle tire with a manual pump.

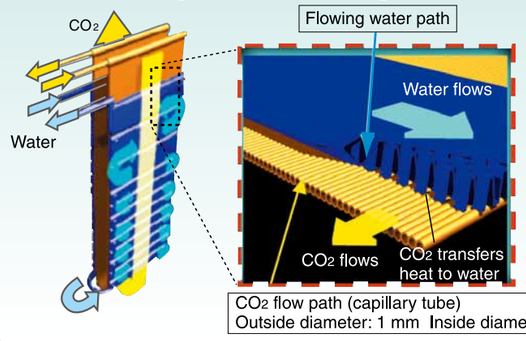


Structure of scroll compressor



Compression method of scroll compressor
Compressing in the order of ①, ②, ③

② Water-Refrigerant Heat Exchanger



Heat exchanger heats water by using the heat of heated refrigerant (CO_2).
→Heated hot water is used for hot water supply and other purposes.
(Temperature of refrigerant goes down to 20℃ from around 130℃, as water deprives it of heat.)

CO_2 flow path (capillary tube)
Outside diameter: 1 mm Inside diameter: 0.5 mm

Electricity
1

100 barometric pressures at 130℃
High temperature
30 barometric pressures at 10℃
CO_2 refrigerant
Compressor
Hot water (90℃)
3-5
Heat water
CO_2 refrigerant cycle
Heat exchanger (for the air)
Heat exchanger (for heating water)
Heat pumped up from the outside air whose temperature is 15℃
2-4
Heat absorbed from the air
Expansion valve
Circulating pump
Low temperature
30 barometric pressures at 5℃
100 barometric pressures at 20℃
Water (15℃)

③ Expansion Valve

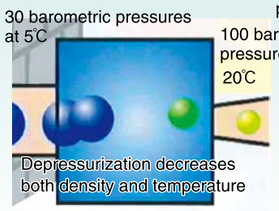
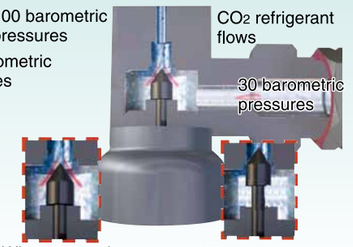


Image Drawing of Expansion Valve

Mechanism of expansion valve

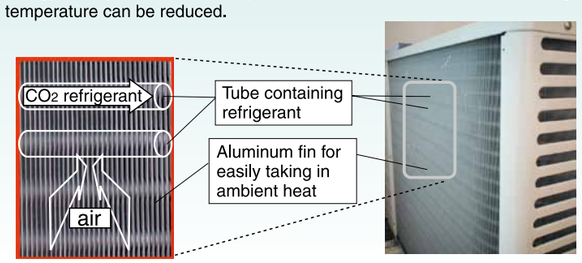


When expansion valve opens.
When expansion valve closes.

Inflated refrigerant (CO_2) decreases outside air temperatures down to -10℃.
→Even if outside temperature is 0℃, rapidly inflated refrigerant can bring temperatures lower than outside temperature.
→Spray can gets colder on the same principle, when you continue pushing its head.

④ Air-Refrigerant Heat Exchanger

By using ambient heat etc., increase the temperature of refrigerant (CO_2) (For example, from 5℃ to 10℃)
→By increasing the temperature of refrigerant to some extent, amount of energy to be placed onto a compressor at the process of ① to produce high temperature can be reduced.



Gases in general have a nature of heating up under pressure and cooling down when inflated. Using such a nature, heat pump takes in outside ambient heat by cycling refrigerant (CO_2), capable of efficiently giving and taking in heat, thus producing large amount of heat, while consuming less energy. Hot water heated by this technology is used for hot water supply and other purposes.

Building a "Low-Carbon Society" with Heat Pumps

The synergistic effect of increasing energy efficiency on the demand side through utilization of ambient heat energy and an increase in shares of non-fossil fuels on the supply side contributes to building a low-carbon society.

Merit to Supply Structure

Decarbonization in energy supply

- ○ Improvement in self-sufficiency through expansion of utilization of nuclear energy and renewable energy, efficient utilization of fossil fuels, etc.
- ○ Combination of various energy sources in consideration of their characteristics to reinforce energy security.

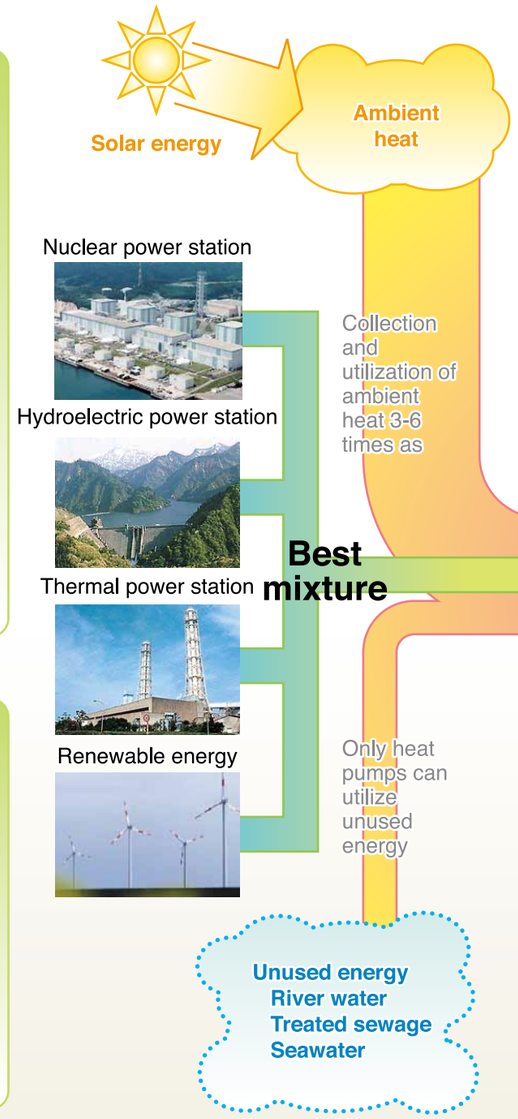
Aiming at the cutting-edge energy supply and demand structure

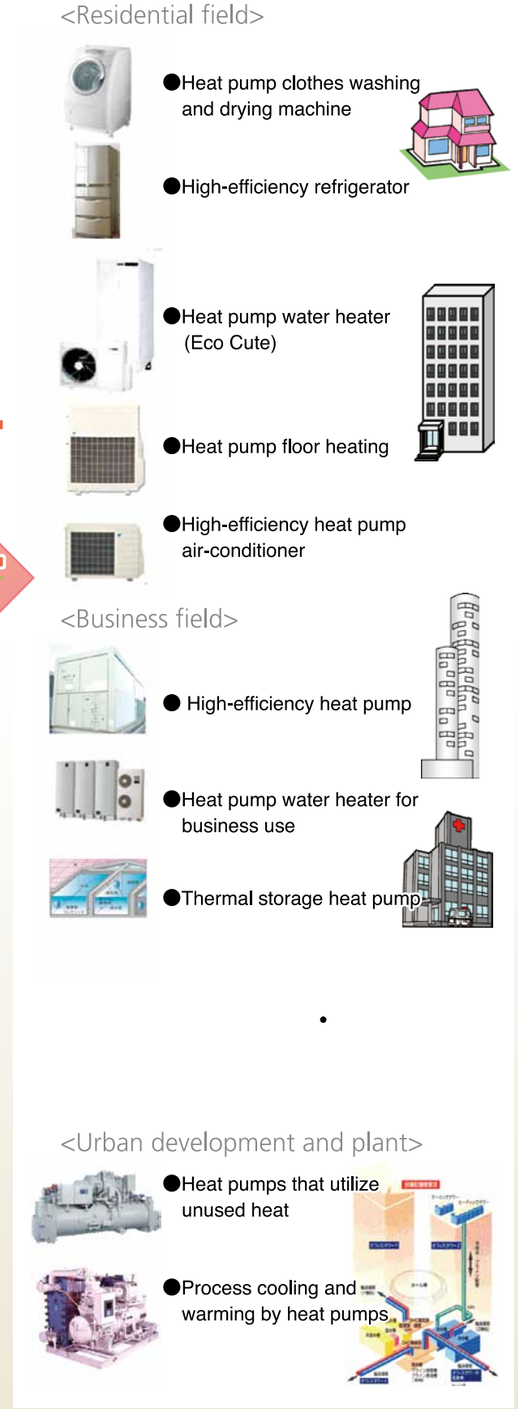
- ○ Diversification and decentralization of energy sources
- ○ Maintenance of appropriate surplus energy supply capacity to cope with tight supply and demand
- ○ Promotion of carbon-free nuclear energy

Heat Pumps also Contribute to Stabilization of Supply Systems.

- ○ Wider use of highly efficient heat pumps constrains the peak of energy consumption.
- ○ Increased use of thermal storage systems contributes to the progress in terms of load leveling.

→ Surplus energy supply capacity increases (In the case of Japan, if 20 million units of Eco Cute are installed (one out of every two households), the share of nuclear energy exceeds 50%.)





Merit to Demand Structure

Creation of CO_2-free society

- ○ Efforts not to emit CO_2 at places of demand are necessary.
- ○ Reduction in dependence on primary energy (direct combustion of fossil fuels)
- ○ Shift to utilization of secondary energy (electric power) and renewable energy (wind power and ambient heat)
- ○ Heat energy in the air (energy conservation) is homemade energy.

Heat pump technology as a carbon-free technology

- ○ Heat energy produced by combustion is replaced with ambient heat energy.
- ○ Heat pump technology that can produce heat energy without combustion is a carbon-free technology.

Achievement of energy load leveling

- ○ Promotion of load leveling of energy is effective for efficient operation of equipment. Energy cost is also reduced.
- ○ It is possible to shift daytime energy demand for air-conditioning to nighttime, and create energy demand for hot water supply during nighttime by combining heat pumps with thermal storage systems as the "energy utilization technology that goes beyond time and space."
- ○ The use of heat pumps in combination with electricity storage systems is also effective.

Toward a Demand System not Dependent on Fossil Fuels

Supply System not Dependent on Fossil Fuels

Utilization of mature and established power transmission and distribution networks

Universal infrastructure that has been built up over the years

- ○ Quick restoration of overhead line systems damaged by major earthquakes, etc.
- ○ No need to invest in new infrastructure

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