Moonshot R&D MILLENNIA* Program

*Multifaceted investigation challenge for new normal initiatives program

"Feasibility study of Moderately-Decentralized Society Based on Multi-scale Energy Harvesting and Storing System

July, 2021

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Contents

I. Concept of Target proposal for MS

1. Target proposal for MS

1.1. Title of the target proposal for MS

- **To archive a "HO・DO・HO・DO" decentralized autonomous network society that will be free from limited energy usage by 2050".**

Here, “being free from energy” means that human beings can harvest a sufficient amount of energy from nature and that the harvesting and use of this energy does not affect the global environment.

Note; Title of the target proposal for MS when this project was started

- To achieve a decentralized autonomous network society based on the concept of “HO·DO·HO·DO” through energy harvest and circulation

1.2. Social image that should become real

“HO·DO·HO·DO” is a Japanese perception, meaning “appropriate, do not push oneself too hard, feel equal, and make a decent living with comfort,” which leads to the well-being of people. At the root of Japanese well-being, the notion of sharing and circulation is accomplished via teamwork by taking the balance with others into account.

This concept of “HO·DO·HO·DO” is fundamental to the achievement of a sustainable society, and similar to “Mottainai” this idea should be proudly propagated today.

For achieving a decentralized autonomous network society based on the concept of “HO·DO·HO·DO,” our goal is to establish an “energy harvest and circulation system” using cutting-edge technology to generate, store, and transport energy. Recent technological revolution has resulted in the remarkable development of energy-saving functions, including highly advanced heat accumulation systems, which are used in industries such as electric power generation, iron and steel, super-insulated housing construction, and traffic and transportation. Owing to these advances, people can live on half the current energy generated from nature as renewable energy. Heat accumulation systems have also been used to store and transport energy. For instance, in an electrochemical method of energy storage, ammonia is stored and transported to generate hydrogen. Together, such methods are used to create an energy network that considers thorough heat cascade usage as well as energy quantity and quality. This process is based on scientific evidence regarding the fact that an improved efficiency of heat utilization ultimately improves the efficiency of all systems, regardless of the energy form.

Those who invest and participate in community energy can select a locally generated or regional cascade by using energy in the first place, and if the resultant energy is not sufficient, they can adopt other regional energy sources. Furthermore, they can use energy generated from their hometown and reminiscent of the local area with a name tag. Consequently, such a society can share natural energy along with climate, thermal gas, and warmth of human kindness beyond time and space.

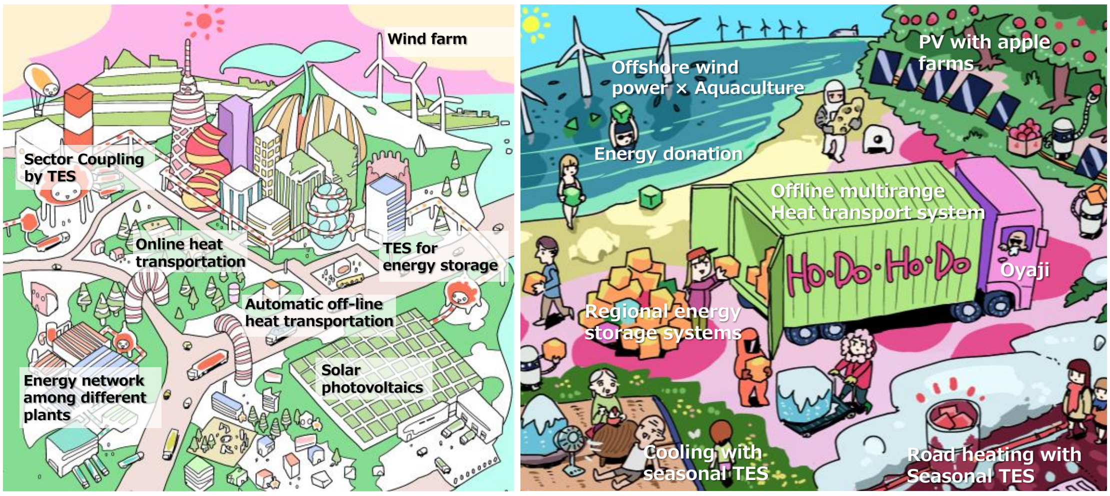


Fig. I-1　Social image that should become real
“To archive a "HO・DO・HO・DO” decentralized autonomous
network society that will be free from limited energy usage by 2050".

2. Targets (Image of accomplishment: What is to be achieved by 2030 and 2050?)

Target 1:

To achieve 50% energy reduction through complete use of exhaust gas by 2050 (2020 criterion) (2030: achieve over 20% energy conservation in some areas)

Target 2:

To generate renewable energy that suits the climate, build a system through which energy is shared and circulated among the habitants of the region, and create renewable energy that meets the demand for current energy usage (2030: achieve over 50% energy conservation in some areas)

Target 3:

To connect information value and energy by 2050 and add new value to regional outbound productions and services (2030: test-introduction of regional energy "green" tokens)
The newly added values are tagged (when, where, and who generated; terms of storage; assurance of quality; and recycle mark) traceable, and exchangeable over long distances through information technology.

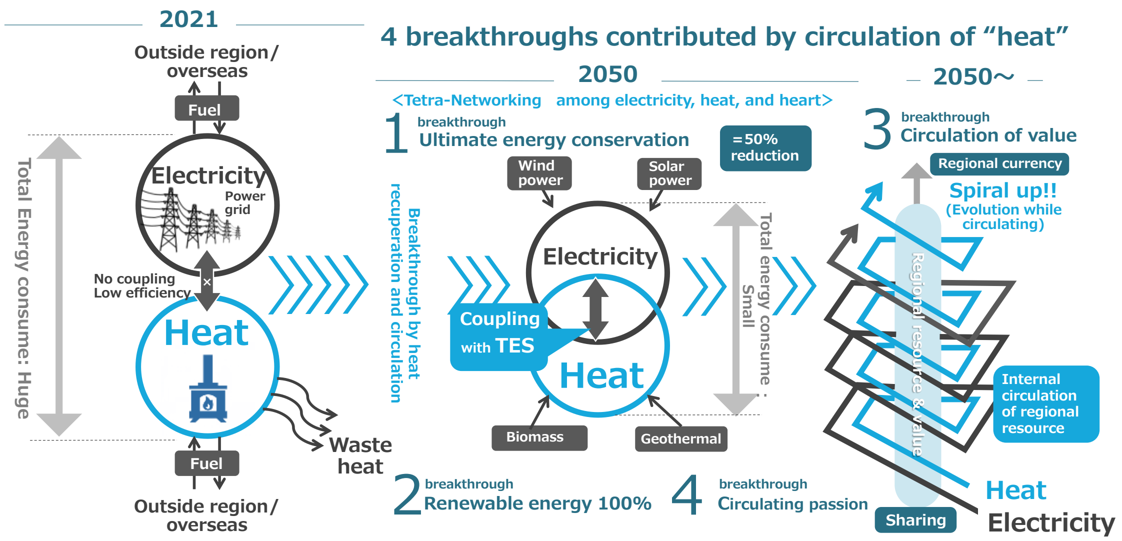


Fig. I-2 Tetra-Networking among electricity, heat, value, and passion.

3. Reason behind this proposal and social meaning of accomplishment

3.1. Why must the target be tackled now?

What is "HO·DO·HO·DO?"

"HO・DO・HO・DO" is a viewpoint of the Japanese that means "appropriate, do not push oneself too hard, feel equal, and make a decent living with comfort," which leads to the "belief of balance with others, common direction, and that happiness will eventually come around"; that is, the Japanese form of happiness (cooperative form of happiness that differs from the acquisitional happiness represented by the realization of self-worth promoted in North America)[1].

Our current society is the result of excessive and detached human activities, such as the abuse of the limited natural resources and the release of pollutants (for example, greenhouse gases), which far exceed the global capacity, thereby threatening the human society. "HO・DO・HO・DO" signifies "sustainability", and this can be said to express the essence of humans living as part of the global natural environment.

This sense of "HO・DO・HO・DO" is similar to the Danish "Hygge" (a word that describes how Danes spend their time and how they feel, such as feeling cozy, safe, and comfortable) or the Swedish "Lagom" (which means "not too much or too little, just the right amount", which

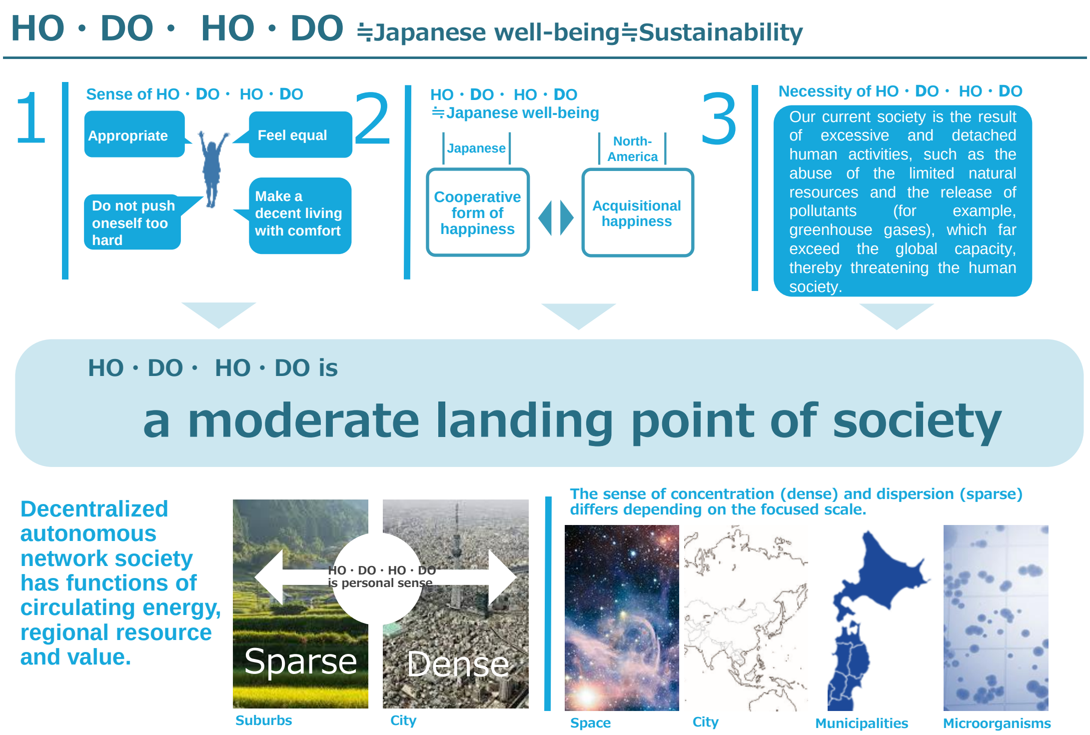


Fig. I-3 HO・DO・HO・DO≒Japanese well-being≒Sustainability is a concept that Swedes value above all else in their lives)[2)]; hence, this is not an exclusively Japanese concept. Scandinavia also views welfare and the environment as important policies, sharing a common perspective with the Japanese, who value “sustainability”.

Human activities prior to the Industrial Revolution were within the carrying capacity of the earth (it would be more accurate to say that this was due to technological and social constraints, and that it happened naturally). It is not our intention to say that we must return to this type of lifestyle. The current aim should be for humans, who have once gone into excess, must independently become conscious of the concept of “HO・DO・HO・DO”, which they previously unconsciously felt, while not working too hard or enduring too much as they go from expansion to contraction, and finding just the right landing point. This means, taking a new journey to evolve to this next stage.

It was believed that setting the goal of focusing on energy that could not be independently controlled, despite the indications that fossil fuel energy is finite, and that human survival is at risk due to global warming is currently needed for a positive transformation into a “HO・DO・HO・DO” society.

What is an appropriately decentralized autonomous network society?

The meaning of decentralization depends on scale. For instance, a colony of microorganisms is sporadic on a Patri dish, but microorganisms are crowded within the colony. Similarly, cities exist sporadically on the Earth’s surface, but the cities themselves are densely populated. Considering such differences in perspective, it is difficult to unequivocally answer the question of a reasonable medium between centralization (congestion) and decentralization (sparse), and it appears impossible to define a moderately dispersive society.

In this proposal, HO·DO·HO·DO indicates sustainable energy use, or “circulation” in a broad sense. In this system, sufficient environmentally friendly energy is generated and shared. The components sharing energy may be a family, neighborhood, or settlement and other regions, thereby creating a multiscale network. Thus, the counterpart is a friend that shares and passes this value. Therefore, an appropriately decentralized network society would be a society that fully circulates energy or value at multiple scales.

We then support the mechanism that enables the cooperation between regions with excess and deficiency, wherein energy that suits the local environment can be effectively used with new value while exchanging energy between regions, thereby evolving as a society. It was hypothesized that there was a need for such a mechanism that could help the society move forward with regional power.

The reason this must be tackled now

- Climate change caused by greenhouse gas emission through anthropogenic activities must be urgently mitigated.
- In addition to the reduction of greenhouse gas emission by 80% to avoid breaching the 2°C limit by 2050, Japan has declared a net zero emission scenario.
- The global COVID-19 pandemic has accelerated the shift to a decentralized society.
- An overconcentrated society leads to depopulation in rural areas, economic stringency, and shift to an aging population, along with reduction in the number of children. Together, these circumstances lead to the collapse of local communities.
- In general, there is some disagreement regarding the shift to a decentralized society, considering diversification as a risk at the time of disaster. However, social systems and employment in local towns are not well developed; it is difficult to build new infrastructure in a society under such circumstances, thereby often warranting a breakthrough.

3.2. Social meaning of accomplishment

1) The effects of climate change are minimized, thus contributing to human well-being.
2) Achieving a foundation for life using renewable energy enables the flow of funds from the outside to the inside of a region, creating new opportunities for employment and avoiding overconcentration.
3) The choice of clothing, food, and housing is expanded. Personal desire to live wherever one wishes is fulfilled (without overconcentration or extreme decentralization), thereby enabling people to make decent, stress-free living).
4) Shift to a decentralized society is facilitated, which avoids disasters, such as pandemics.
5) The energy gap is reduced. For instance, space required for building power plants is decreased.
6) If renewable energy is environment friendly, shared, and circulated by a community whose inhabitants invest in energy, the cooperate sector can be merged with the public sector, which contributes to the revitalization of the local communities.
7) Renewable energy use and energy conservation by circular utilization in and between regions could be dramatically improved through the introduction of regional currency.

3.3. Details of social effort in general to achieve the target for MS

1) Core technology development sector

- Heat circulation medium and system development

2) Related technology development sector

- Energy harvesting technology
- Looping technology on a large time and distance scale
- Ultimate energy saving
- Heat revitalization
- Robust heat (energy) storage technology
- Electricity/heat-integrated management system using heat storage material

3）Technology application sectors

- Industrial fields (electricity, gas, heat supply, water services, mining, manufacturing, agriculture, among others)
- Consumer sector (construction industry, accommodation industry, and various service industries)
- Transportation sector (transportation industry, among others)
- Technological applications required in all sectors in addition to the aforementioned

4) Social technology sector

- Common renewable energy and formulation of morals (institution, consortium, and education)
- Creation of a value-exchange role for using renewable energy (economy, low, and system)
- Division of roles in the society

5) Information technology sector

- Energy traceability, tagged technology
- Value exchange system using blockchain technology
- Compatible with social issues, such as individual information management

6) Government sector

- Agreement with measures and policies for citizens in the region
- Launch and operation of local communities (citizen-funded joint ventures)
- Collaboration with other public sectors, such as education, welfare, and community transportation

4. Social and industrial changes through the accomplishment of the target

- Achieve energy conservation (dramatic improvements in efficiency through the use of heat storage material) that far exceeds the energy conservation performance of Japan (efficiency, heat insulation), which has been established since the oil crisis in 1970s. Dramatic energy conservation will be achieved particularly in the electricity, mining, and manufacturing fields. Marked improvement in the global competitiveness of the Japanese industry can be achieved, which contributes to a sustainable society from a global perspective and simultaneously contributes to global sustainability with energy conservation technology originating from Japan.

- Achieve the maximum use of renewable energy suited for each local environment (such as solar power, wind power, geothermal power, or biomass) and promotion of various energy-related careers, including in electricity storage, hydrogen, and heat storage according to the need of the population (storage period, transportation distance). Create new energy-related employment based on the internal circulation of energy revenue that used to flow out from the region. The proportion of the population in the region involved in renewable energy will increase, and there will be accumulation of technological know-how and development of human resources that are suited for the local environment.

- Establish a carbon-neutral and environmental pollutant-free distribution system (transmission lines, pipelines, and vehicle transportation, among others). A mechanism (community) will emerge in the medium- to long-term where citizens themselves invest in and support social infrastructures that can serve as assets for the next generation.

- Technologies that allow energy users to select the energy production area, harvest year, storage method, and period will be developed, and individuals will be able to sense in their daily lives that they are acting in a carbon-neutral way and contributing to sustainability on a regional, national, and global scale.

- Individuals can choose to live in regions that suit their lifestyle and will be able to engage in energy-based communication that allows them interact, appreciate, and connect with friends who share mutual beliefs.

- An independent and distributed networking society is attained wherein everyone can choose their own diverse lifestyles, thereby forming a distinctive and attractive community that suits the local environment throughout Japan while alleviating the pressures on forming centralized cities.

II. Statistics: Supervising the analysis

1. Challenges (social and technological) in accomplishing the target and necessary measures to overcome them

1) Scenario for net-zero greenhouse gas emission by 2050

Following the industrial revolution, anthropogenic use of fossil fuels increased remarkably, which improved productivity and increased population (Fig. II-1). According to the United Nations, the population is expected to reach 11 billion by 2100 (https://population.un.org/wpp/Graphs/Probabilistic/POP/TOT/900). In particular, the population in Asia and Africa is expected to increase dramatically.

Fig. II-1: World population shift

(Reference: United Nations Population Fund, Tokyo Office website)

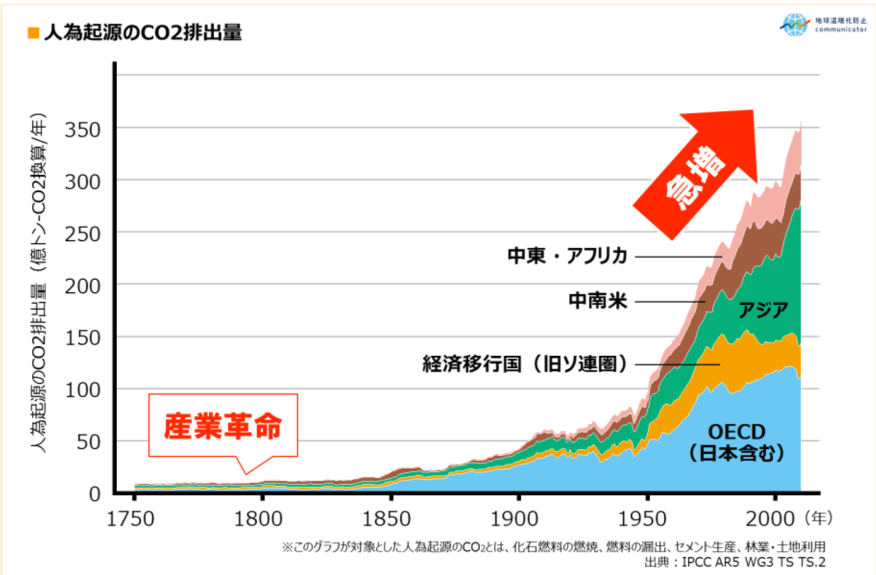


Fig. II-2: Anthropogenic CO_2 emission

(Reference: Ministry of Environment website)

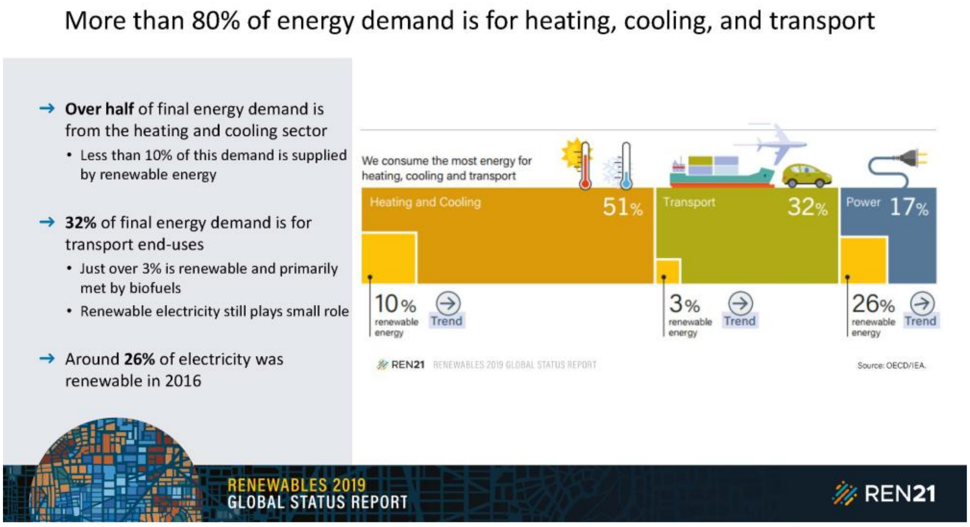


Fig. II-3: Energy usage and share of renewable energy

(Reference: REN21, Renewables 2019 Global Status Report, 2019)

Furthermore, anthropogenic CO_2 emissions have risen sharply since 1950, with the atmospheric CO_2 concentration reaching 450 ppm in 2020 from approximately 354 ppm in 1985 (https://ds.data.jma.go.jp/ghg/kanshi/ghgp/co2_trend. html).

According to the Fifth Assessment Report (2013) on Climate Change by the International Panel on Climate Change (IPCC), anthropogenic activities have extremely high potential (over 95%) to cause global warming, and since the mid-20th century, atmospheric carbon dioxide, methane, and dinitrogen monoxide concentrations have significantly increased to unprecedented levels over the eight hundred thousand years. To mitigate greenhouse gas emission in the post-2020 period, the Paris Agreement was adopted as a new international framework at the Paris Climate Conference (COP21) in December 2015. On October 28, 2020, Japanese Prime Minister Suga announced that Japan will attain zero-emission and a carbon neutral society by 2050. In response to this announcement, the Japanese economies and industries have accelerated the movement to shift toward a carbon-neutral society.

As shown in in Fig. Ⅱ-3, 51% of the energy used in the world is in the form of heat, and only 10% of it is renewable. The proportion of energy used for transportation and electricity generation is 32% and 17%, of which only is 2% and 26% is renewable, respectively (REN21, 2019).

In May 2021, the International Energy Agency published “NET ZERO by 2050,” indicating a scenario and road map by 2050. In the net zero emission (NZE) scenario, all energy supply (Fig. Ⅱ-4) from most fossil fuels is expected to be replaced by renewable and nuclear energy, thereby decreasing the share of fossil fuels from 80% to 20% in 2050. Moreover, as shown in Fig. Ⅱ-5, considering 24% increase in anthropogenic activities from 2020 to 2030, the aim of reducing CO_2 emission can be achieved through electrification; carbon capture, utilization, and storage (CCUS); behavior and avoided demand; use of wind and solar energy; use of hydrogen-based energy; increase in energy efficiency; and shift to other fuel sources, such as bioenergy. Among these, CCUS, behavior and avoided demand, and the use of hydrogen-based energy are anticipated to substantially reduce Co2 emissions in the post-2030 period.

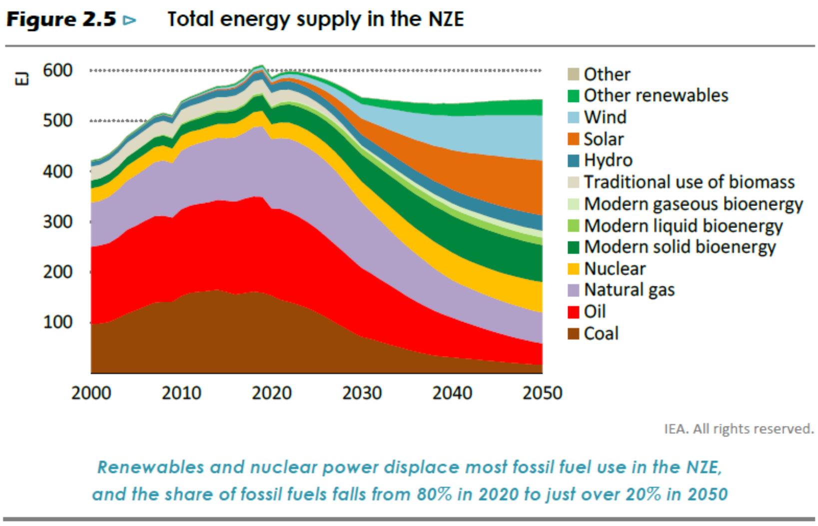


Fig. Ⅱ-4: Total energy supply in the NET ZERO scenario by 2050 (Reference: IEA, NET ZERO by 2050, 2021)

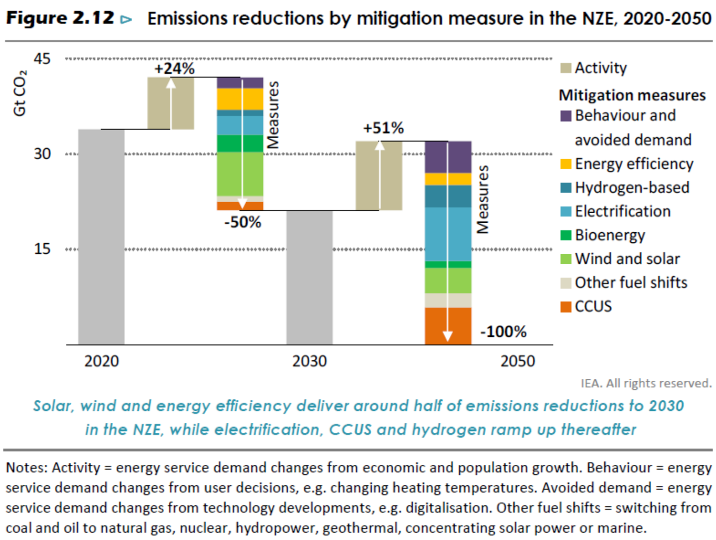


Fig. Ⅱ-5: Mitigation measure to reduce CO_2 emissions in the NET ZERO scenario by 2050 (Reference: IEA, NET ZERO by 2050, 2021)

Moreover, among renewable energy, the proportion of solar and wind power has been forecasted to increase significantly from 29% in 2020 to almost 90% in 2050.

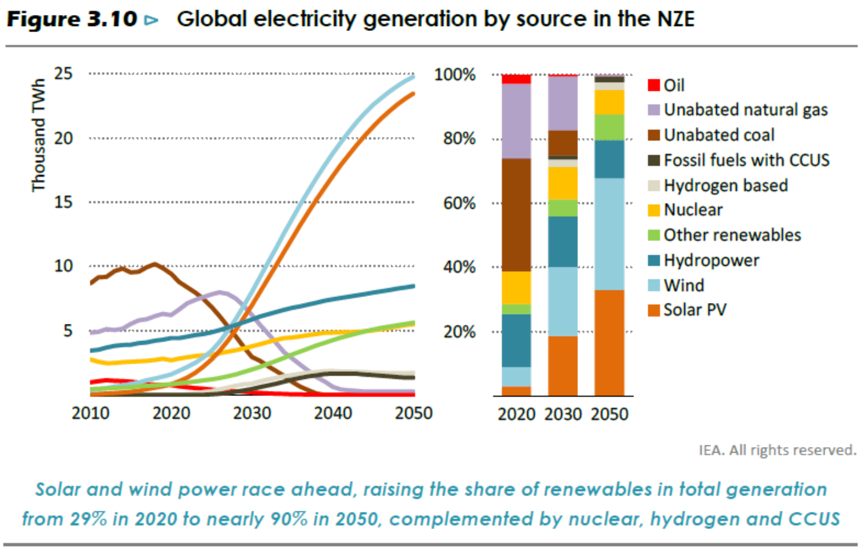


Fig. Ⅱ-6: Date of electricity generation by the source in the NET ZERO scenario by 2050

(Reference: IEA, NET ZERO by 2050, 2021)

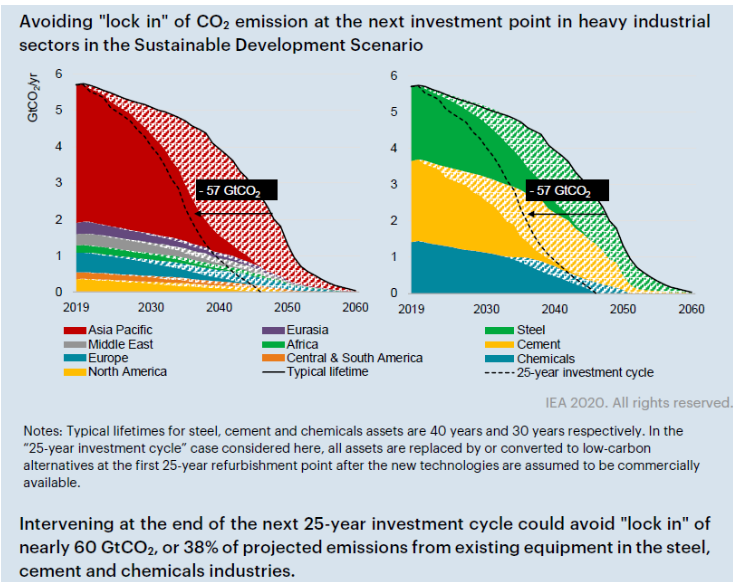


Fig. Ⅱ-7: Scenario of reduction in CO_2 emissions from the iron and steel, cement, and chemical industries

(Reference: IEA, Energy Technology Perspectives, 2020)

In various industries, drastic measures such as equipment replacement are requested within 25 years, particularly in heavy industrial sectors (such as iron and steel, cement, and chemicals), regardless of the next date of replacement. The main sources of heat in light industries, such as electric heaters heat pumps, and biomass, are used to maintain low-to-moderate temperatures (0 to 400°C). Meanwhile, electric heaters, hydrogen heaters, and biomass are the main sources of heat required to maintain temperatures exceeding 400°C. Heat demand is expanding in the mining, construction, Tobacco, and machine industries.

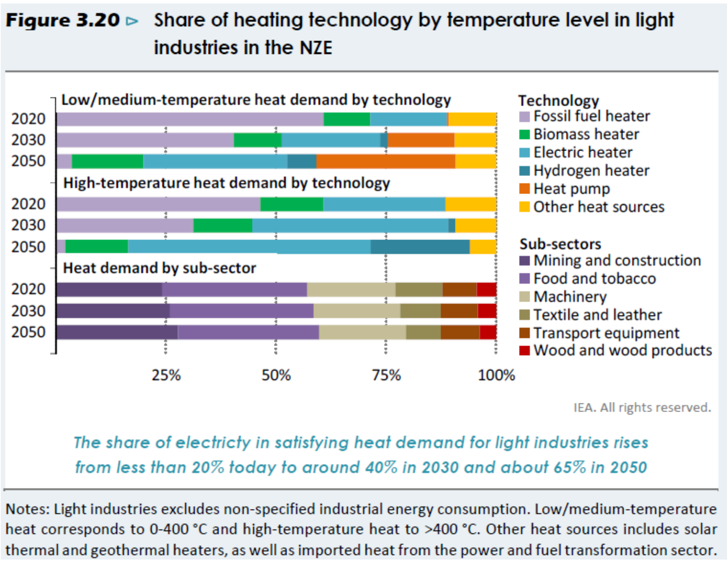


Fig. Ⅱ-8: Share of heating technology by temperature level in light industries in the NET ZERO scenario by 2050
(Reference: IEA, NET ZERO by 2050, 2021)

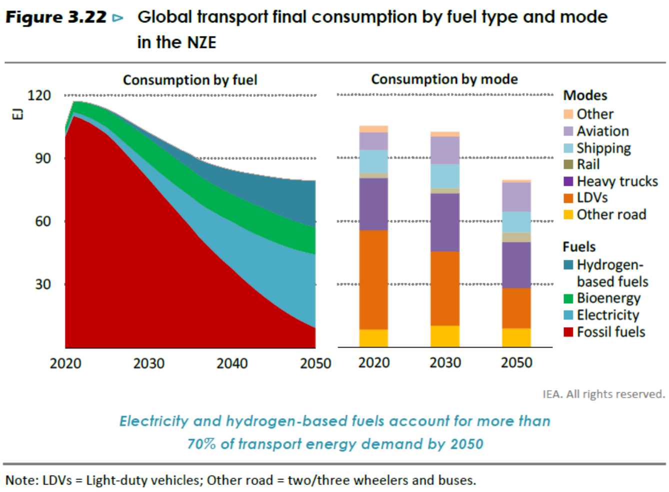


Fig. Ⅱ-9: Global transportation final consumption by fuel type and mode in the NET ZERO scenario by 2050
(Reference: IEA, NET ZERO by 2050, 2021)

In the transportation sector, fossil fuels are replaced by electricity, hydrogen, and biomass, which have become mainstream. In addition, the development of energy-efficient family cars has considerably reduced energy consumption.

Moreover, thanks to the progress of energy-efficient technologies, fossil fuel use in the construction industry is forecasted to decline by 96% and essential energy use with regard to heat is expected to reduce by two-third in 2050.

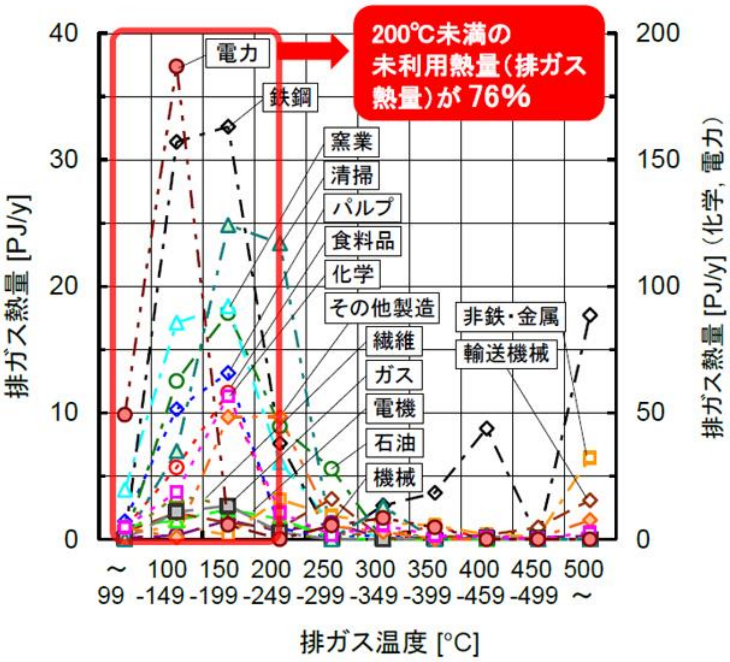


Fig. Ⅱ-11: Global estimated data of unutilized heat quantity (exhaust gas) in the industry-classified sector (chemistry and power are on the right side)
(Reference: NEDO, Research report about actual condition of exhaust gas in industrial sector, 2019, https://www.nedo.go.jp/news/press/AA5_101074.html)

3) Challenges in introduction of renewable energy

According to the IEA, renewable energy (particularly solar and wind power) will become the main source of electricity in NZE by 2050 and fossil fuel use will decrease to 20%. Solar and wind power is called variable renewable energy (VRE), which fluctuates with the balance of day and night and temperature, and VRE is expected to account for 60% of power by 2050. To use VRE as the primary energy resource, adjustments for fluctuations would be required to the entire supply system. To address this, effective storage batteries are one of the tools for short-term storage and hydrogen batteries are an option for seasonal long-term storage.

4) Overview of thermal energy storage for utilizing various energy sources

Thermal energy storage (TES) has drawn worldwide attention in recent years. As shown in Fig.Ⅱ-12, TES can accommodate surplus energy derived from solar and wind power, thus reducing the time of power conditioning and providing flexibility to meet a sharp drop and rise in demand. In terms of power transportation, TES avoids or postpones large amounts of investments for power line network enhancement. It can use renewable energy generated and left in the summer to meet the heating demands in the winter through seasonal storage. In addition, the heating and cooling load patterns can be improved by connecting multiple sectors. As the demand for renewable energy as power increases, depending on the power alone, the overall cost also increases. TES is an essential component for comprehensively controlling power, heating, and cooling; however, it eventually limits the electric power transmission capacity. In other words, we can use renewable energy at a reasonable price as much as possible. As shown in Fig. Ⅱ-13, technological developments in TES have been studied at various temperature ranges by hours, days, and months. Table II-1 summarizes the TES technology illustrated in Fig. Ⅱ-13 in addition to other technologies (Fig. II-14 to II-19).

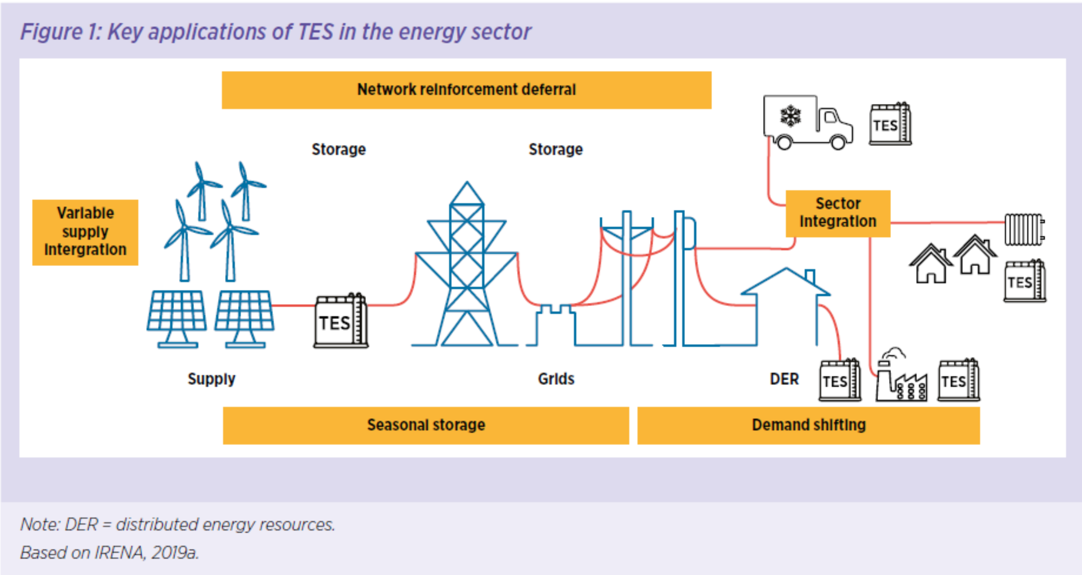


Fig. Ⅱ-12: TES usage in the energy sector
(Reference: IRENA, Innovation Outlook Thermal Energy Storage, 2020)

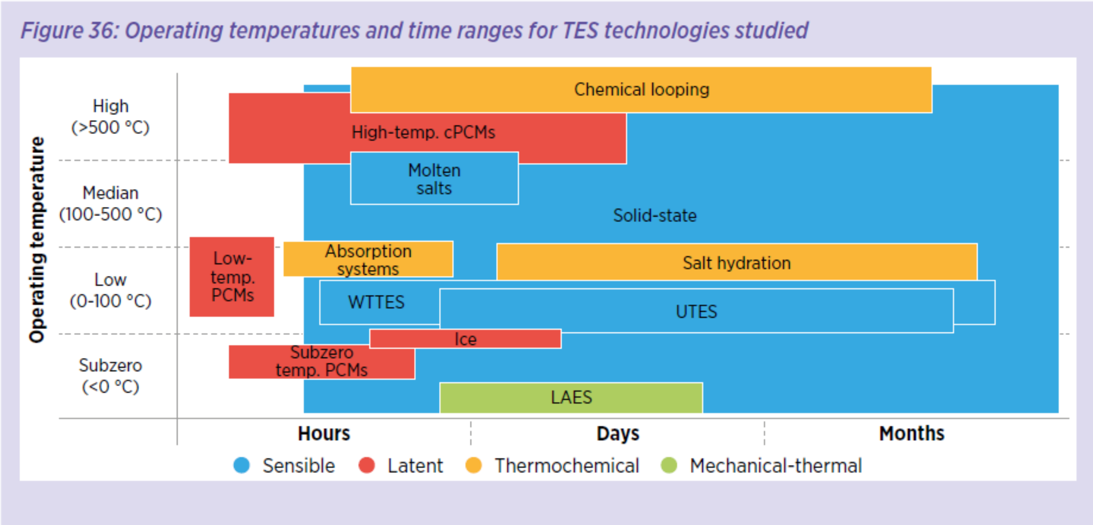


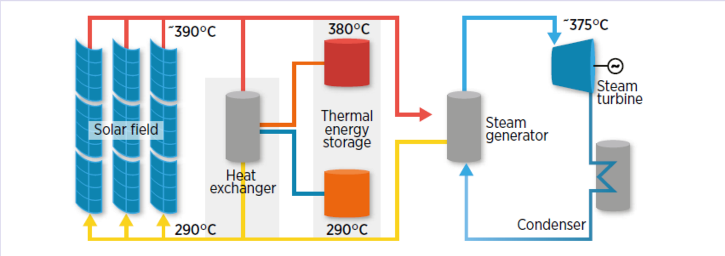
Fig. Ⅱ-13: TES usage in the energy sector

(Reference: IRENA, Innovation Outlook Thermal Energy Storage, 2020)

Table Ⅱ-1: TES technology

Category	Name	Details	Figures
Sensible heat storage	Tank thermal energy storage (TTES)	Usage of water: WTTES	
	Solid-state thermal storage	Usage of brick, stone and concrete	
	Molten salts	Usage of molten salt	Fig. Ⅱ-14
	Underground thermal energy storage (UTES)	Usage of underground space (soil and groundwater)	Fig. Ⅱ-15
Latent heat storage	Ice thermal storage	Usage of Ice	
	Sub-zero temperature PCMs	Latent heat storage material in sub-zero temperature zones	Fig. Ⅱ-16
	Low-temperature PCMs	Latent heat storage material in low-temperature zones	Fig. Ⅱ-16
	High-temperature PCMs	Latent heat storage material in high-temperature zones	Fig. Ⅱ-16
Thermochemical energy storage	Chemical looping	$CaO \longleftrightarrow CaCO_3$	Fig. Ⅱ-17
	Salt hydration	Hydrating salts	
	Absorption system	Absorption method	
Mechanical–thermal-coupled system	Compressed air energy storage	Heat storage using compression air	Fig. Ⅱ-18
	Liquid air energy storage	Heat storage using liquid air	Fig. Ⅱ-19

Figure 25: Indirect molten-salt storage system

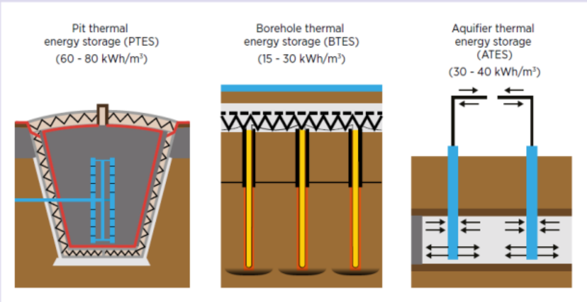


Source: Archimede Solar Energy, 2020.

Fig. Ⅱ-14: Molten salt storage system

(Reference: IRENA, Innovation Outlook Thermal Energy Storage, 2020)

Figure 26: Underground energy storage concept

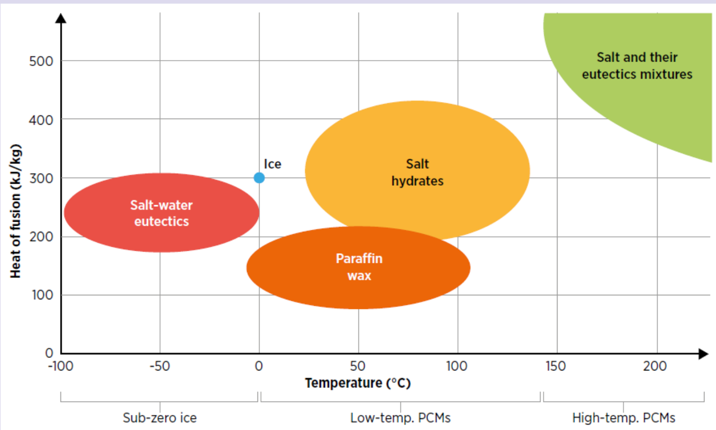


Source: European Association for Storage of Energy and European Energy Research Alliance, 2017a.

Fig. Ⅱ-15: Underground energy storage system

(Reference: IRENA, Innovation Outlook Thermal Energy Storage, 2020)

Figure 27: Properties of PCMs examined in this report, showing difference in heat of fusion and melting points



Note: kJ/kg = kilojoules per kilogram.

Fig. Ⅱ-16: Association of temperature zones with latent heat storage materials

(Reference: IRENA, Innovation Outlook Thermal Energy Storage, 2020)

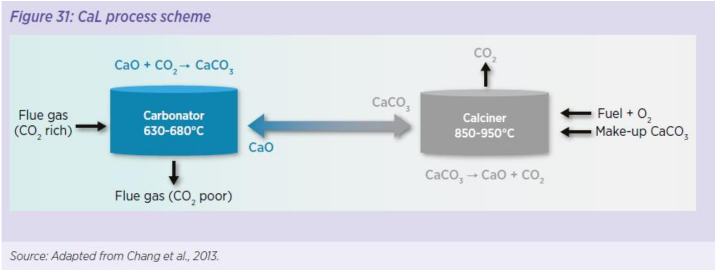


Fig. II-17: Ca looping

(Reference: IRENA, Innovation Outlook Thermal Energy Storage, 2020)

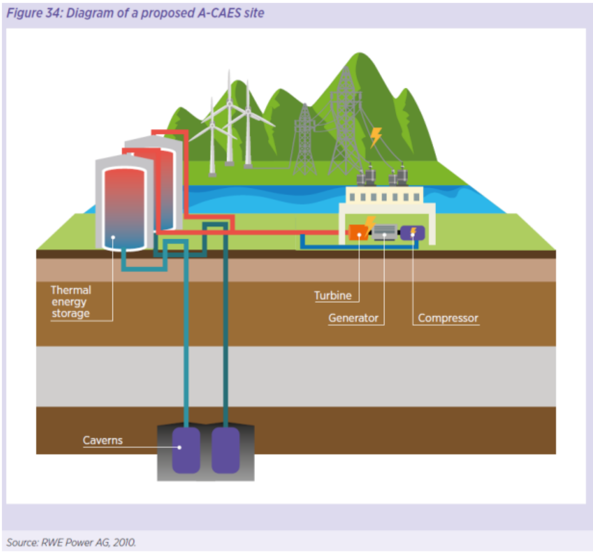


Fig. Ⅱ-18: Heat storage system using compressed air

(Reference: IRENA, Innovation Outlook Thermal Energy Storage, 2020)

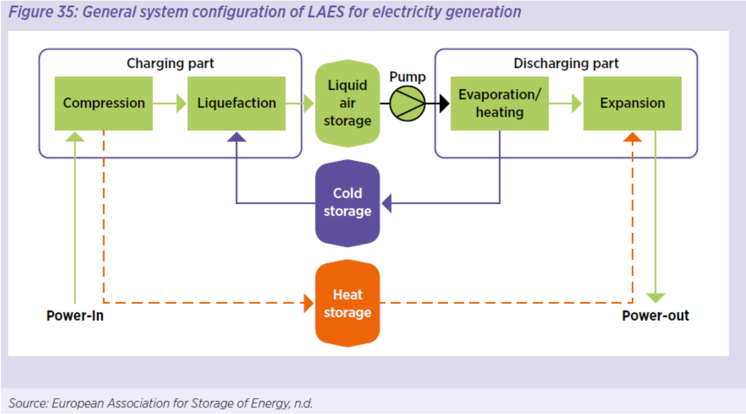


Fig. Ⅱ-19: Heat storage system using liquid air
(Reference: IRENA, Innovation Outlook Thermal Energy Storage, 2020)

TES has wide application areas since TES is not only applied as energy storage systems that utilize its principles and features as it is, but also because it is a technology that supports it as the basis of various heat-related technologies such as heat utilization, heat transport, heat control, and heat retention of buildings and equipment. Figs. II-20 to II-24 show targets progress in the development of TES and development goals for 2030 in the power, industry, cold chain, district heating and cooling, and buildings sector. The development targets of latent heat and chemical heat storage, which are still as advanced TES technologies, are shifting to relatively higher temperature areas expect for the cold chain sector. Advancing TES of energy storage for VRE is a main reason for the technology shift of latent and chemical heat storage. In other words, from 2030 and beyond, TES is required to play a role as a technology that couples power generation from renewable energy and heat utilization in other sectors. Current situation of development of heat storage technology and current phases of heat storage technology are shown in Table II-2 and II-3, respectively.

Fig. Ⅱ-21: Progress in the development of heat storage materials in the industrial sector and development goals for 2030

(Reference: IRENA, Innovation Outlook Thermal Energy Storage, 2020)

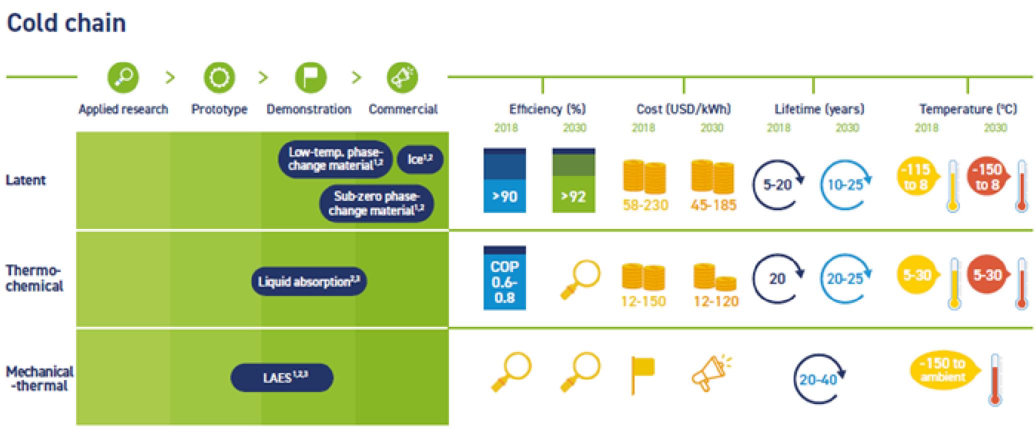


Fig. Ⅱ-22: Progress in the development of heat storage materials in the cold chain and development goals for 2030

(Reference: IRENA, Innovation Outlook Thermal Energy Storage, 2020)

Fig. Ⅱ-23: Progress in the development of heat storage materials for regional heating and cooling systems and development goals for 2030

(Reference: IRENA, Innovation Outlook Thermal Energy Storage, 2020)

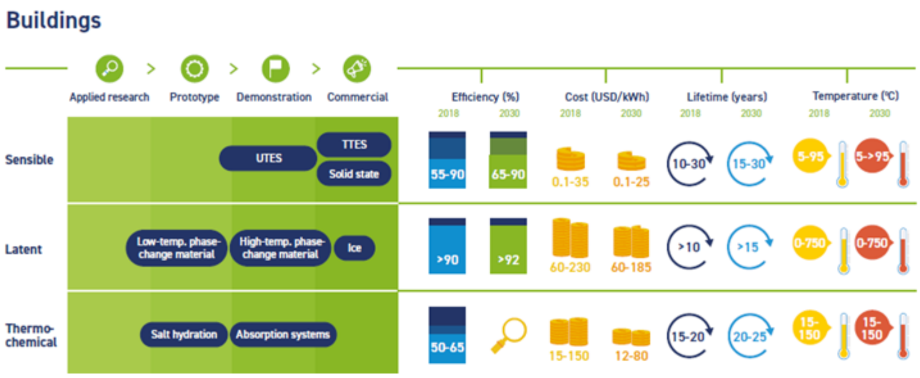


Fig. Ⅱ-24: Progress in the development of heat storage materials in the construction sector and development goals for 2030

(Reference：IRENA, Innovation Outlook Thermal Energy Storage, 2020)

Table Ⅱ-2: *Current situation of development of heat storage technology

蓄熱技術		発電部門	産業部門	コールドチェーン部門	地域熱供給部門	建造物部門
顕熱	TTES, WTTES		Commercial		Commercial	Commercial
	Solid-state	Demonstration	Prototype		Prototype	Commercial
	Molten salts	Commercial				
	UTES				Commercial	Demonstration
潜熱	Ice			Commercial	Commercial	Commercial
	Sub-zero PCMs			Demonstration / Commercial	Applied research / Prototype	
	Low-temp PCMs			Demonstration / Commercial		Applied research / Prototype
	High-temp PCMs	Applied research / Prototype	Prototype / Demonstration		Demonstration	Demonstration
熱化学	Chemical looping	Applied research / Prototype	Applied research / Prototype			
	Salt hydration	Applied research	Prototype / Demonstration		Prototype / Demonstration	Prototype
	Absorption			Demonstration	Prototype / Demonstration	Demonstration
機械熱力学	CAE	Prototype / Demonstration				
	LAES	Prototype		Prototype / Demonstration		

(dark green)	Commercial
(green)	Demonstration
(light green)	Prototype
(yellow)	Applied research
(white)	None

Table Ⅱ-3: *Current phases of heat storage technology

(Reference: IRENA, Innovation Outlook Thermal Energy Storage, 2020)

Table 3: Key technical attributes of selected TES technologies

Type of TES	TES technology	Range of capacities	Range of power	Operating temp-erature	Round-trip efficiency	Storage period	Energy density	Lifetime (years or no. of cycles)
Sensible	WTTES	kWh to 1 GWh	kW to 10 MW	10 to 90°C	50 to 90%	Hours to months	15-80 kWh/m^3 (1)	15-40 years
	UTES	MWh to GWh	MW to 100 MW	5 to 95°C	up to 90%	Weeks to months	25-85 kWh/m^3	50 years
	Solid state	10 kWh to GWh	kW to 100 MW	-160 to 1 300°C	>90%	Hours to months	0.4-0.9 kWh/m^3·K (heat capacity) (2)	> 5 000 cycles
	Molten salts	MWh to 5 GWh	100 kW to 300 MW	265 to 565°C (4)	>98%	Hours to days	70-200 kWh/m^3	> 20 years
Latent	Ice thermal energy storage	kWh to 100 MWh	kW to 10 MW	-3 to 3°C	>95%	Hours to days	92 kWh/m^3	> 20 years
	Sub-zero temperature PCM	kWh to 100 kWh	kW to 10 kW	down to -114°C	>90%	Hours	30-85 kWh/m^3	> 20 years
	Low-temperature PCM	kWh to 100 kWh	kW to 10 kW	up to 120°C	>90%	Hours	56-60 kWh/m^3	300-3 000 cycles
	High-temperature cPCM	10 kWh to GWh	10 kW to 100 MW	up to 1 000°C	>90%	Hours to days	30-85 kWh/m^3	> 5 000 cycles
Thermo-chemical	Chemical looping (calcium looping) (5)	MWh to 100 MWh	10 kW to 1 MW	500 to 900°C	45-63%	Months	800-1200 kWh/m^3	>30 years
	Salt hydration	10 kWh to 100 kWh	N/A	30 to 200°C	50% (open systems) 60% (closed systems)	Months	200-350 kWh/m^3	20 years
	Absorption Systems	10 kWh to 100 kWh	10 kW to 1 MW	5 to 165°C	COP: 0.7-1.7	Hours to days	180-310 kWh/m^3	50 years
Mechanical-thermal systems	CAES	10 to 1 000 MWh	10 to 1000 MW	up to 600°C	> 90% (thermal efficiency)	Hours to weeks	N/A	20-40 years
	LAES	MWh to GWh	10 to 300 MW	> 300°C (heat) -150°C (cold) -196°C (liquid air)	> 90% (thermal efficiency)	Hours to months	N/A	> 25 years

Notes: (1) The energy density of water TTES and UTES is based on a reference temperature at 20°C; sensible heat is not considered in the calculation of energy density of latent heat storage; (2) Energy density of solid state is determined by the operating temperature difference; energy density = heat capacity x temperature difference; (3) for "solar salt" (60% $NaNO_3$ and 40% KNO_3); (4) Only referring to calcium looping process (as opposed to other chemical looping examples); kW = kilowatt; MW = megawatt; MWh = megawatt hour; COP = coefficient of performance.

Note: N/A dennotes that no main needs were identified.

5) R& D trends related to major TES technologies

Next, R & D trends related to major TES technologies will be described.

(1) TES

TES using sensible heat is at the demonstration/commercial level. Regenerative heat exchangers that use solid sensible heat storage materials, such as hot blast furnaces and regenerative burners, have been the basic technology for heat utilization in the current industry. In addition, with the progress of concentrated solar power plant, a large-scale molten salt sensible heat storage system using nitrates mixtures (Operating temp. < 565°C) has been commercialized. Furthermore, in recent years, the development of heat storage technology (commonly known as Carnot battery or electric thermal energy storage as an energy storage technology for VRE has been widely progressing. Carnot battery is a "Power-Heat-Power" type energy storage technology for stably utilizing VRE. Table II-4 shows ongoing projects of Carnot battery. Sensible heat storage technologies using molten salt or rock are trends of development due to their low capital cost. On the other hand, considering the sector coupling with industry and consumer affairs, the development of advanced heat storage technology is required in the future.

Table Ⅱ-4: Examples of thermal energy system for grid-scale energy storage[12-15)]

Company/Project	SIEMENS Gamesa RNEWABLE ENERGY	STORASOL GmbH	MAN Energy Solutions	Malta Inc.
Storage method	Sensible	Sensible	Sensible	Sensible
Storage material	Rock	Sand	Water	Molten salt
Storage temp. [°C]	～750	～1000	120～	～565
Storage capacity	130 [MWh_{th}]	50 – 1000 [MWh_{th}]	-	(100 MW_e×10 h)
Volume of storage unit [m^3]	800	-	-	-
Status	Real scale pilot demonstrating	Under development (Target for commercial availability is 2024)	Under development	Under development (First commercial project online in 2024 or 2025)

TES using latent heat is at the commercial level for technologies using ice, but there is still room for research and development regarding phase change materials (PCMs) in a wide range of temperature ranges, such as in the power generation, industrial, district heating, and building sectors. Research and development on heat storage technology, as solar thermal power generation and energy storage technology, as well as latent heat storage technology in high-temperature zones that targets industrial waste heat recovery, have recently shown progress. Since latent heat storage technology in high-temperature zones requires the use of refractory substances such as molten salts, metals, and alloys as PCMs, overcoming the corrosiveness between heat storage tanks/heat transfer equipment and PCMs has been the primary constrain. Certain solutions for some PCMs (such as Al-Si

PCMs) have been found by coating the heat transfer surface and heat storage tank with ceramics, with some projects aiming for commercialization being planned[16]. Furthermore, the use of ceramics for corrosion resistance and mechanical strength during use or processing, not only in the high-temperature zones but also a wide range of other temperature zones, has become a subject for technological development, and development of micro-capsule PCMs that use SiO_2[17] or Al_2O_3[18] as shells is ongoing. New fields that use ceramics as PCMs are also emerging[19]. Table II-5 lists examples of recent advance of new PCMs. Japan is at the forefront in the development of these new materials, which can be applied not only for the purpose of simple heat storage but also to various heat-related technologies such as particle transfer-based heat transport as well as heat control. Notably, this is important as a new technological area that spans all sectors, such as power generation, industry, district heating, and construction. Establishment of a low-cost, mass-production technology for these new materials, as well as the development of integrated devices, processes, and systems that joins both industry and academia are needed in the future.

Table II-5 Examples of technology on new-generation PCMS[17-19]

Technology	Core-shell type micro encapsulated PCMs	Core-shell type micro encapsulated PCMs	Heat storage ceramics
Storage material	Alloy PCMs/Al_2O_3 shell	Salt hydrate PCMs/SiO_2 shell	Oxide
Phase change	Solid-Liquid	Solid-Liquid	Solid-Solid
Target storage temp. [°C]	～800	< 150	About ～300
Storage density [GJ m^{-3}]	～1.0	～0.43	～0.23
Status	Laboratory	Laboratory	Laboratory

Table II-6 Examples of projects on large-scale chemical heat storage system[20-22]

Company	AICHI STEEL CORPORATION/ Toyota Central R&D Labs., Inc.	TOYOTA Motor Corporation, etc.	Salt X Technology
Storage method	Chemical heat	Chemical heat	Chemical heat
Storage material	CaO-H_2O	MgO-H_2O	Nano-coated CaO-H_2O
Storage temp. [°C]	～427	200～250	～550
Storage density of storage unit [GJ m^{-3}]	0.57	～1.0	-
Status	Real scale pilot demonstrating	Pilot demonstrating	Pilot demonstrating

TES using chemical heat is a under developing technology, especially in the power generation and industrial sectors. Since chemical heat storage uses the reaction heat of a reversible chemical reaction, higher heat storage density is possible relative to sensible and latent heat application. However, the repeated durability of the chemical heat storage materials used (pulverization is the main issue) and heat exchange performance continue to be relevant constrains. Solutions to these problems have recently been found for some reaction systems (particularly CaO-H_2O systems), and practical applications for waste heat recovery technologies are emerging. Table II-6 lists examples of projects of chemical heat storage. In Japan, the recovery of electric furnace exhaust heat [20] and heat transport between factories[21] have been demonstrated, and the construction of a 1 MW/15 MWh-class pilot plant has also been planned overseas for the purpose of recovering factory exhaust heat[22]. Moreover, there is a need for comprehensive research and development of materials and processes that match the demands of the industry based on the premise of addressing the aforementioned limitations, such as chemical heat pumps that can upgrade the lower-temperature industrial waste heat by equilibrium operations and reuse it as a heat source.

Heat storage technologies using mechanical energy are still at the prototype to demonstration stage as an energy storage technology. Compressed air energy storage (CAES) with a high-temperature heat storage system[23] and liquid air energy storage that stores liquid air at −190°C as energy[24] are in the demonstration stage.

(2) Overview of heat transport technology

To achieve circulation and provision of energy via heat, technology to transport heat becomes necessary. For spatial transport, online or offline heat transport can be considered. In addition, development of heat storage and transport beyond “time” to accommodate regional characteristics is important.

For offline heat transport, technologies such as container truck with PCM, chemical thermal storage medium, and adsorption heat storage materials are being developed. Table II-7 shows the test cases for such technologies. Among the common challenges in all systems are the high initial and running costs, and the resulting long payback period. While high-density heat transport per batch is required, if heat exchange performance of the system is poor, the number of times heat that can be transported is reduced, eliminating the difference in the amount of heat transported within its lifetime. In addition, while the importance of using thermal energy is being recognized, the low price of heat as energy is a factor that interferes with its popularity.

Concerning online heat transport technology, heat transport by heat pipe has been developed and used over 100 years especially in Scandinavia. In Japan, district heat supply is often introduced when formulating new urban plans. In recent cases, such a plan was incorporated into the new city development[27]. In the future, assuming the use of renewable energy as the energy source in the online heat transport of district heat supply, development of an energy storage technology with a function to stabilize unstable power source (≒ heat source) and the ability to coproduce electricity and heat, as well as its integration with the district heat supply system, are necessary.

Table II -7: Examples of technology of off-line heat transportation [21, 25, 26]

Company	Sanki ENGINEERING CO., LTD.	Waseda University etc.	Takasago Thermal Engineering Co., Ltd. etc.	TOYOTA Motor Corporation, etc.
Storage method	Latent heat/Sensible	Adsorption	Adsorption	Chemical heat
Storage material	Erythritol	Zeolite	HAS-Clay	$MgO-H_2O$
Storage temp. [°C]	About 120	About 180	80～120	200～250
Storage density of storage unit [GJ m^{-3}]	0.24	0.56	0.59	～1.0
Status	Commercially available	Bench scale	Real scale pilot demonstrating	Pilot demonstrating

3) Overview of heat recuperating and circulating technology

Based on the exergy recuperating theory that demonstrates the theoretical goal of heat use from a thermodynamics perspective, conversion from the conventional cascading use to exergy recuperating technology can achieve innovative energy conservation (～85% smaller input than conventional systems). Figure II-25 shows its principle[28].

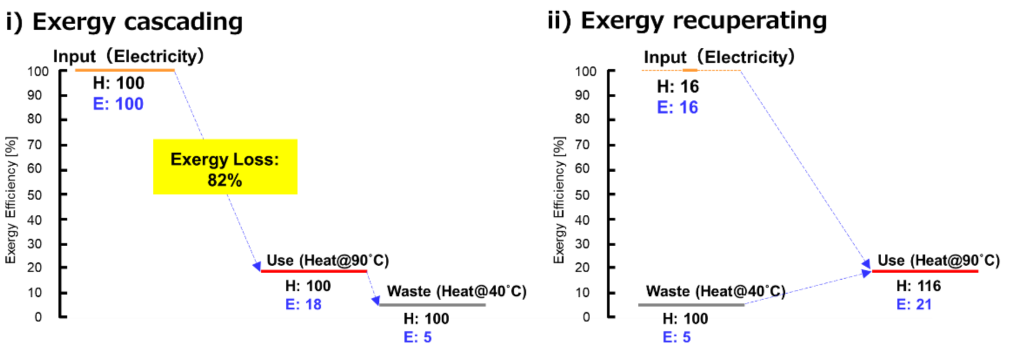


Fig. II -25: Exergy cascading V.S. Exergy recuperating

The exergy recuperating technology allows the recuperating low-quality used heat as high-quality energy, such as electricity, to achieve its circular use. This exergy recuperating theory[29] and technology is being developed as a Japanese technology, achieving the implementation of a distillation process. Table II-8 shows some examples. In principle, this technological system can be implemented in all range of temperatures; however, the existing technology is only able to accommodate up to approximately 200 ℃. In part, this limitation is due to the lack of technologies to upgrade heat by efficiently inputting "work" that can assume temperature ranges over 200 ℃ (since the existing technologies require the use of a compressor, which is unable to accommodate higher temperature ranges). Moreover, to achieve higher efficiency, the temperature difference during heat exchange must be set as low as possible (= pinch temperature), thereby requiring a large heat exchanger and high facility cost as a result.

Table Ⅱ-8 Examples of projects on exergy recuperation technology[30-32]

Company	Tokyo Univ./NIPPON STEEL ENGINEERING CO., LTD.	Mitsubishi Chemical Engineering Corporation	Daicel Corporation
Principle	Self-heat recuperation	Self-heat recuperation	Vapor Re Compression
Application	Distillation plant for Bio-Ethanol	Distillation plant	Distillation plant
Operating temperature [°C]	< 200 (Estimation)	< 200 (Estimation)	< 200 (Estimation)
Status	Real scale pilot demonstration@2012	Commercially available	Commercially available

(4) Heat control technology

With the paradigm of the existing industry and heat use technology, a large amount of low-temperature heat emission, as shown in Figure II-11, and the establishment of a technology for its effective use constitute the main challenges.

In NEDO project “Research and Development Project on Innovative Thermal Management Materials and Technologies（Implementation period: FY2015 to FY2022）” [33], as a technology to reduce waste heat (≈ unused thermal energy), heat insulation and heat insulation technology have been developed along with heat storage, and various variable results have been being reported. On the other hand, the main waste heat source in high temperature processes in steelmaking industry is the sensible heat of products. In the steel industry, products are adjusted to the desired structures and compositions by precisely misting the high-temperature slab surface with water and steam, and cooling it. Thus, the sprayed water and steam become low-temperature heat emission sources. In NEDO " CO_2 Ultimate Reduction System for Cool Earth 50 (COURSE50) Project", in the process of commercializing steelmaking slag, which is a by-product of the steelmaking industry, an advanced approach to recover this high-temperature sensible heat was demonstrated[34]. To recover the product heat itself are currently positioned as an extremely challenging technology.

Furthermore, in several exothermic processes in chemical plants, temperatures must be constant during an operation; thus, to achieve stable operations at well-controlled temperature, the heat of the reaction must be cooled with cold water. Therefore, this process generates a large amount of low-temperature heat. If such heat generated in the exothermic process can be converted to a stable heat source and used as the heat source for endothermic processes, a heat-emission-free process can be achieved.

6) Social challenges

(1) Challenges for business entities

Japan spends tens of trillions of JPY on procuring fuel oil and natural gas from other countries, because there are no sufficient energy resources in the country. Fig. Ⅱ-26 presents the proportion of expenditure for energy relative to the gross regional production in Japan. Overall, 90% of energy expenditure is red in local towns across the country, with 70% of the local towns spending 5% of regional gross production on energy and 115 local towns experiencing over 10% of funding leak[35].

If adaptable renewable energy is generated and used in these region, new employment opportunities can be created and funding leak can be prevented.

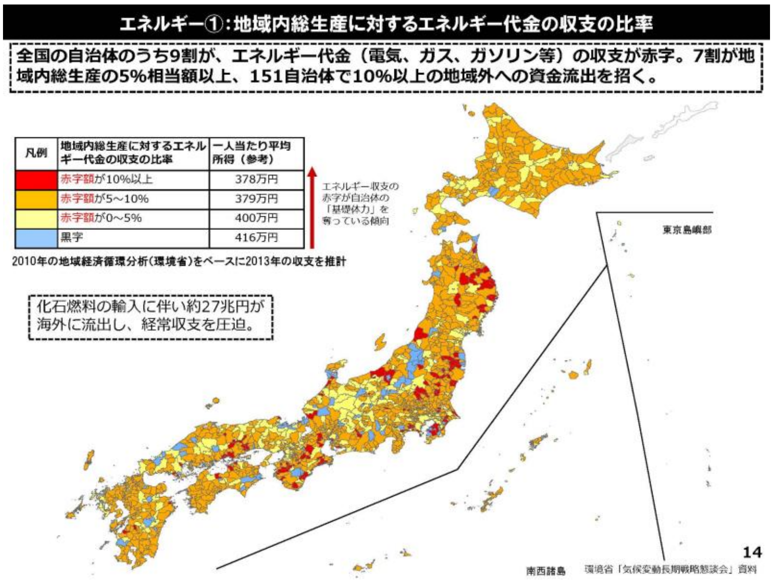


Fig. Ⅱ-26: Proportion of energy expenditure relative to the regional gross production (Reference: Ministry of the Environment website)

A scheme is essential to promote the local production and consumption of energy, which can uplift the regional economy. The public business sector is under the jurisdiction of the government, and this business is practiced under the order from the government to the private sector or is undertaken by the government itself in the domestic sector. Generally, energy production falls under the private business sector, which is under the control of the Ministry of Economy. In recent years, a portion of the power industry has changed, triggering free power retailing, division of transmission and distribution, and revolution of power generation and retailing. With these changes, regional power companies that deal with renewable energy have started businesses in many parts of the country. Such companies are jointly funded by the government and private sector, and increasing number of companies appear to be following this mode of business.

For instance, Stadtwerke is a public utility in Germany and Oesterreich. It undertakes a wide range of public services, such as power supply. It provides intensive and comprehensive infrastructure-related services (power, water, and transportation), and most stocks are generally held by the local towns (Fig. II-27)[36].

Fig. Ⅱ-27: Details of Stadtwerke (an example)

(Reference: http://kinki.env.go.jp/11%20%28HP%E6%8E%B2%E8%BC%89%E7%94%A8%29%E7%AB%8B%E5%91%BD%E9%A4%A8%E5%A4%A7%E5%AD%A6%E3%83%A9%E3%82%A6%E3%83%91%E3%83%83%E3%83%8F%E6%95%99%E6%8E%88%E8%B3%87%E6%96%99.pdf)

Although Japan once considered the Japanese version of Stadtwerke, the idea remained unclear in terms of the difference between the so called third sector that was developed by 100% investments from public corporations and co-funding from private businesses. This concept has also been criticized as being a revolving door. Given these ambiguities, extensive discussion is warranted. Even though this is public work, improvements in function and management are required to match the standards in the private business sector. Professor Raupach Joerg of the Ritsumeikan University has compared the Japanese and German versions of Stadtwerke and highlighted some challenges, as shown in Fig. Ⅱ-28[36].

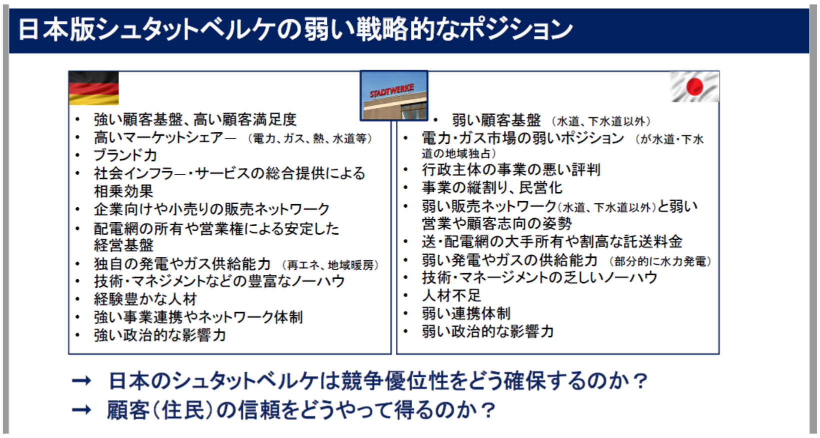


Fig. Ⅱ-27: Challenges in the Japanese version of Stadtwerke

(Reference: http://kinki.env.go.jp/11%20%28HP%E6%8E%B2%E8%BC%89%E7%94%A8%29%E7%AB%8B%E5%91%BD%E9%A4%A8%E5%A4%A7%E5%AD%A6%E3%83%A9%E3%82%A6%E3%83%91%E3%83%83%E3%83%8F%E6%95%99%E6%8E%88%E8%B3%87%E6%96%99.pdf)

An enterprise to achieve locally grown and consumed renewable energy is desirable. How likely is such an enterprise to create investment and agreement? What are the roles and divisions of citizens, communities, and private businesses? These questions warrant discussion, along with the establishment of a business operation policy and design of institutional arrangements.

(2) Challenges in building a regional community

To apply renewable energy that is suitable for the region and share it with others, we must reconsider it as a regional resource to be shared. For instance, energy derived from the nature is common. By considering it as a common resource, the conflicts among citizens can be minimized and over-hunting can be prevented, leading to reduced environmental impact. With respect to energy usage and governance being community services jointly funded by citizens, there will be new social roles and structural reforms for occupation in the region.

Based on these roles, a new community will be formed in the region. In addition, some structures such as regional currency are essential, which can allow citizens to exchange the value of energy or various other things, thus solving the problems of education and welfare. Businesses that fill the gaps in activity between the government and private companies and share values that are inconvertible to currency have been in demand. Funds for energy purchase as well as social capital, such as “bonds” and “thoughtfulness,” have dispersed from the region, which are essential to form a regional community.

If such a community generates, uses, and shares regional renewable energy to form a new value and regional community in which all inhabitants get along well, it can serve as the foundation of the entire system. Such a system can promote to the growth of human resources and those who support it.

7) Operating the regional community based on information technology

According to Sasakawa[37)], among the 200 (in 36 countries) examples of blockchain technology, most represented decentralized energy usage (88 examples). The author exemplified a decentralized energy deal that archived the power bargain between the prosumer and user; thanks to the blockchain technology, the user can acquire the information of purchased power easily. In Germany, the power source certification has been institutionalized according to the EU order since 2001. From a technical perspective, a payment system can be built using a blockchain while maintaining traceability.

However, according to Sasakawa[37)], the blockchain technology cannot maintain the balance between demand and supply or stabilize power supply all by itself. The author also argues that as evidenced in Germany, it is more important to encourage the construction of a cooperative framework including electric power providers and enterprises, which has its strengths in terms of infrastructural aspects, such as alignment with supply and demand by adjusting the market or installation and expansion of smart meters and blockchain technology.

Overall, to create regional systems that use and consume local renewable energy, maintenance of the information infrastructure requires collaboration with companies that exhibit functions of power management and strength in the blockchain.

8）ELSI

To achieve the presently proposed society, multiscale trust must be built among diverse stakeholders (such as citizens, government, and businesses) that constitute the communities within a region, including the relationship between each individual. Concerning the harvest, storage, transport, and use of renewable energy, common social capital and values need to be formed. Transactions (value exchange) need to be performed based on such common values.

Introduction of the local currency as a cryptocurrency that uses the above-mentioned blockchain is one method to achieve this. Trust in such currency is essential for its continuous and expanded use in the region; therefore, to achieve this trust, personal information must be strictly managed and appropriately handled based on informed consent.

Moreover, once such trust is built within the communities in a region, circulation of the new value obtained from energy transactions may spread to public services, such as education, welfare, and transit. Management of personal information, which forms its foundation, must be stipulated not only by international and domestic regulations but also by rules for the communities.

2. Supervising research and development for the accomplishment of the target for MS

To achieve the present MS targets, mass introduction of renewable energy, electrification, and use of hydrogen must take place simultaneously. At the same time, integration/fusion of technologies for storage, transport, renewal, and control of energy based on the heat use, “the axis” of such simultaneous progress with social and information technologies is necessary. An overview of such technologies is given below.

1) Ultimate thermal energy technology

Energy storage technology

Since heat is the energy with the lowest quality, all energy can be converted to heat. Therefore, excess electricity, biomass, and hydrogen that are beyond the storage capacity can be converted to usable heat. Hence, energy storage via heat storage is an extremely robust approach regardless of the type of energy input. Moreover, it is able to temporarily store excessively harvested energy, which can be converted to a form that can be provided in the region. In order to achieve the present MS targets, low cost, high capacity, compactness, high heat-exchange performance (assuming sector coupling with industries), flexibility of energy input and output, and coupling with regional heat supply would be necessary. To that end, the following technological development would be essential:

Heat transport technology

To achieve the present MS targets, technologies to transport and provide heat are necessary. As shown in Table, although there are technologies that have reached demonstration and implementation stages, they have not become widely available despite the presence of societal need for them. Technological development that envisions a heat transport service with higher density and speed that is economically feasible, rather than mere heat storage material, is necessary

Heat recuperating and circulating technology

To achieve the present MS targets, exergy recuperating technology must be developed to upgrade low-quality heat for circular use. Since the purpose of heat use is diverse, longitudinal development of heat recuperating energy over each temperature range is necessary. Therefore, it would be necessary to establish a new exergy recuperating technology that considers not only the efficiency that can be achieved thermodynamically but also the speed and loss generated in a finite amount of time. Hence, the following research and developments are necessary to achieve the present MS targets:

Heat control technology

To achieve the present MS targets, ultimate energy conservation technology that is beyond the conventional technology is necessary. Thus, instead of effectively using low-temperature heat emission as in the existing technologies, switching to a technology that does not emit heat in the first place is necessary. To achieve this, the following research and developments are necessary, although these have been difficult to tackle in the past:

2）Social/information technology

To achieve the present MS targets, integration/fusion of technologies to harvest, store, and transport renewable energy, especially the heat storage technology discussed above, with social and information technologies is necessary. An overview of social and information technologies is provided below.

Formation of the concept (philosophy and ethics)

- **Understanding where the renewable energy stands as a common social capital**
- **Formation of commons and morals**
- **Response to social issues, such as management of personal information**

System and business formats (economy)

- **Flexible system design**
- **Business format that is able to evolve**

Division of roles within the society (sociology)

- **New roles for the industry, government, academia, and citizens**
- **Citizen participation**

Application of blockchain (existing technology: engineering)

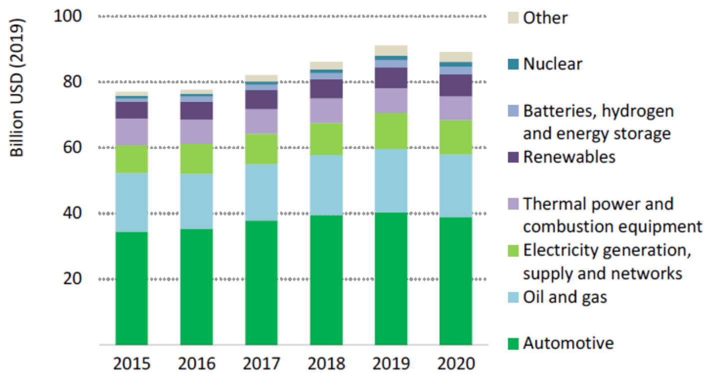
- **Traceability, tagging, and payment systems for energy that use the blockchain technology**
- **Integrated exchange and circulation system for all values concerning logistics, energy, and services within a region**

3. Research development related to the target, overseas trends, and Japan's strengths

1) Research Development Trend of Renewable Energy

Fig. Ⅱ-29 presents the costs of energy-related research and development invested by global companies[38]. From the bar graph, expenditure is mainly focused on automotive, oil and gas, electricity generation, supply and networks, and thermal power and combustion equipment. Little cost is spent on renewable energy. However, dividing these categories seems difficult. For instance, vehicle-related expenditure includes the research and development costs of alternative fuels.

Spending on energy R&D by globally listed companies, by sector of activity



Notes: "Other" comprises coal mining, coal distribution and certain energy efficiency technologies that can be isolated from end-use sectors, such as insulation. Fuel cells are included with hydrogen. Corporate energy R&D spending includes reported R&D expenditure by companies in sectors that are dependent on energy technologies, including energy efficiency technologies where possible. Automotive includes technologies for fuel economy, alternative fuels and alternative drivetrains. To allocate R&D spending for companies active in multiple sectors, shares of revenue per sector are used in the absence of other information. Classifications are based on the Bloomberg Industry Classification System. All publicly reported R&D spending is included, though companies domiciled in countries that do not require disclosure of R&D spending are underrepresented. Depending on the jurisdiction and company, publicly reported corporate R&D spending can include capitalised and non-capitalised costs, from basic research to product development. The total reported here for 2019 is higher than that estimated at the time of publication of World Energy Investment 2020, before all company filings for 2019 were available and before the latest adjustment of sectoral classifications. Spending by oil and gas companies represents the most significant upward revision, USD 1 billion.

Source IEA calculations based on Bloomberg (2021).

Fig. Ⅱ-29: Expenditure on energy-related research and development by global companies (Reference: IEA, World Energy Investment 2021)

The bar chart compares the total amount of national investments in energy-related research and development by country. The highest investments have been made by China, North America, and Europe. Investments by Japan are comparable to those by Korea, Australia, and New Zealand.

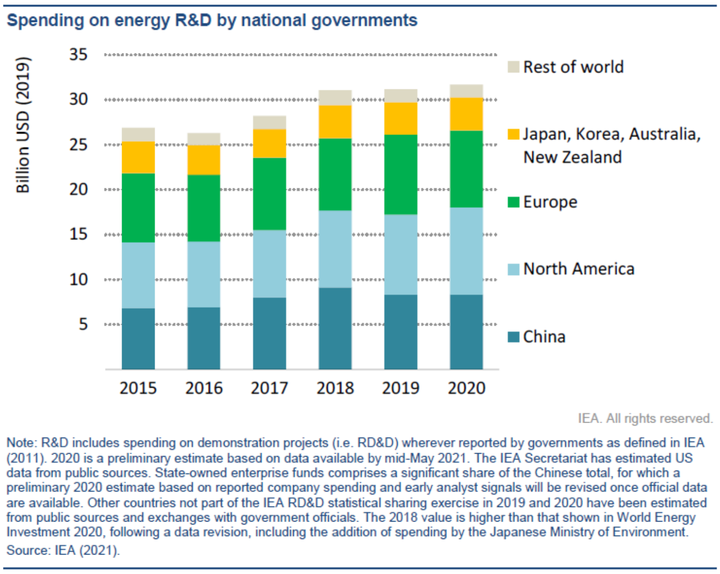


Fig. Ⅱ-30: Expenditure on energy-related research and development by country (Reference: IEA, World Energy Investment 2021)

Fig. Ⅱ-31 illustrates the number of patents related to low-carbon technology in China, Europe, the United States, and Japan[8)]. Europe, the United States, and Japan reached the highest point in 2011, but the values have decreased since then. Japan appears characteristic in the fields of storage and electrical vehicle production, rather than renewable energy. Currently, there is insufficient evidence to show the data related to heat storage.

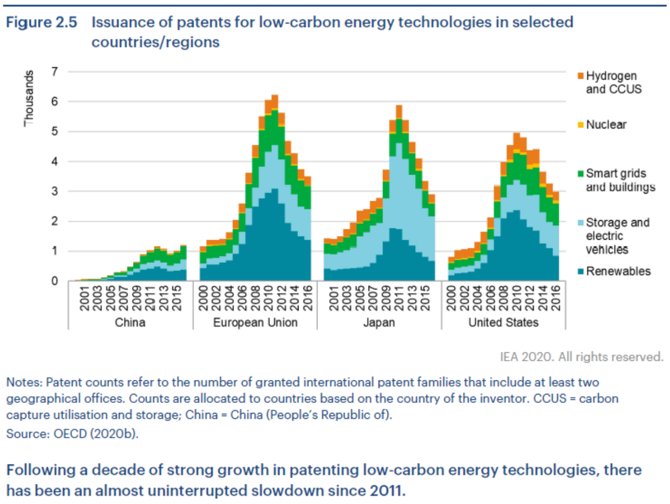


Fig. Ⅱ-31: Issuance of patents for low-carbon energy technologies in selected countries (Reference: IEA, Energy Technology Perspectives 2020)

Table Ⅱ-10 presents the number of reports and countries in the Web of Science.

The search results for "Energy" reached over 3 million hits, with the Japanese reports ranking 4th. Based on the search results for "Coal," "Oil," "Gas," "Nuclear," "Renewable" nuclear, and renewable, Japan ranked 4th in the gas and nuclear energy category and 16th in the renewable energy category, although the contribution rate was lower.

In the categories of renewable energy ("Solar power," "Wind," "Geothermal," "Hydro," and "Biomass"), Japan ranked from 15th to 24th.

In the categories of "Electricity," "Heat," "Thermal," "Cool," and "Fuel", Japan ranked from 4th to 5th, with an advantage on heating usage. In the category of energy storage, Japan ranked 16th in terms of electrical storage and 11th in terms of heat storage.

In addition, Japan ranked from 8th to 11th in the category of heating storage, except for air compression. Overall, Japan appears to have a certain advantage in the field of heating storage.

Table Ⅱ-10: Number of hits for energy-related reports and ranking of Japan

Web of Science 検索ワード　2021.6.12	ヒット数	上位国					日本の順位
		1	2	3	4	5	
Energy	3,124,856	USA	China	Germany	Japan	England	
Energy + Coal	27,769	China	USA	Australia	India	England	Japan (9)
Energy + Oil	64,685	USA	China	India	Canada	England	Japan (11)
Energy + Gas	259,755	USA	China	Germany	Japan	England	
Energy + Nuclear	100,515	USA	Germany	China	Japan	France	
Energy + Renewable	87,859	China	USA	Germany	India	England	Japan (16)
Energy + Renewable + Solar power	12,127	USA	China	India	Germany	Spain	Japan (15)
Energy + Renewable + Wind	19,698	USA	China	India	England	Germany	Japan (17)
Energy + Renewable + Geothermal	2,114	USA	Turkey	China	Italy	Germany	Japan (18)
Energy + Renewable + Hydro	2,375	China	USA	India	Germany	England	Japan (24)
Energy + Renewable + Biomass	12,353	USA	China	India	Italy	Germany	Japan (16)
Energy + Electricity	68,749	USA	China	England	Germany	Spain	Japan (13)
Energy + Heat	263,291	USA	China	Germany	Japan	India	
Energy + Thermal	282,531	USA	China	Germany	India	Japan	
Energy + Cool	70,498	USA	China	Germany	England	Japan	
Energy + Fuel	127,569	USA	China	India	England	Germany	Japan (6)
Energy + Electricity + Storage	12,053	USA	China	Germany	England	Italy	Japan (16)
Energy + thermal + Storage	31,059	China	USA	India	Germany	England	Japan (11)
Energy + sensible heat storage	1,380	USA	China	India	Spain	Germany	Japan (11)
Energy + latent heat storage	5,580	China	USA	India	England	Turkey	Japan (9)
Energy + thermochemical heat storage	916	China	Germany	USA	France	Spain	Japan (8)
Energy + comressed air storage	1,163	China	USA	England	Canada	Iran	Japan (25位以下)
Energy + liquid air storage	1,100	China	USA	England	Germany	Australia	Japan (9)
Energy + PCM	10,529	China	USA	India	Iran	Spain	Japan (13)

III. The Scenario for Realization of Social Image

1. The Challenge in Research and Development Field and Task.

(1) Area and field to promote challenging R&D

In comparison with efficiency of power, heat had been considered as lower efficient energy, but it has been rapidly developed because it expects to cut the cost and technical certainty. Carnot Batterie, reconvert stored heat to power is published as an international cooperative research activity called Annex36 within the International Energy Agency (IEA) and has high expectation for being one of the most significant saving energy technology and societal demand. In Europe where renewable energy is introduced ahead of Japan sees necessity for saving energy technology to use renewable energy efficiently and demonstration tests for large scale of heat storage system such as Carnot Batterie is proactively promoted. Considering that advance in Europe, cooperating with the European research agency is essential because there is sufficient example of research development about mainly targeting on renewable energy in Japan. The other hand, Japan has the most developed technology in terms of saving energy. Collaborating with that agency to promote the research development of heat usage technology proposed in this report will leads achievement of the target to be free from limited energy usage and decentralized autonomous society.

(2) Research subject for realization of MS Goal

I. Core technology development

1) Energy storage technology:

(1-1) Development of thermal storage technology as a robust inter-season energy storage technology

2) Heat transport technology:

(2-1) Development of heat transport systems with high density and high heat-exchange performance

(2-2) Development of fully automated offline heat transport and utilization technology

(2-3) Development of a comprehensive transport system that can integrate other public services (garbage collection, resource recovery, public transit, among other), logistics, and heat transport

3) Heat recuperation and circulation technology:

(4-1) Exergy regeneration technology that can be deployed in various temperature ranges

4) Heat control technology without heat exhaustion:

(4-1) Thermal control technology using coproduction-type endothermic phenomena, such as chemical reactions

(4-2) Control cooling technology that can recover the sensible heat of the product

II. Social technology

1) Positioning and conceptualization of renewable energy as shared social capital

2) Consideration of evolvable systems and business structures that meet the current demands

3) Design of value exchange systems for the use of renewable energy (economic, legal, and institutional)

4) Nudge technology to promote civic behavior change (such as design, art, among other approaches)

5) Organization of new citizen roles and responsibilities, and creation of mechanisms to encourage social participation (self-governance, consensus building, education, among others)

6) Technology for launching and operating local community bodies (citizen-funded joint ventures)

III. Information technology

1) Energy traceability and tagging technology

2) Value exchange technology system based on blockchain technology

3) Integrated exchange and circulation system for all forms of value (intra-regional logistics, energy, and services)

(linked with other public sectors, such as education, welfare, and regional transport)

4) Response to social issues, such as personal information management

2. The Milestones for 2030, 2040 and 2050(Research Development for Milestones and Ripple effect).

① The Milestones to be achieved for 2030, 2040, and 2050

1) Energy storage

2030: *Demonstration of a thermal storage system in a demonstration plant as an energy storage system (test operation*)

2040: *Widespread use of thermal storage systems as energy storage systems and expansion of sector coupling*

2050: Realization of an energy circulation (energy sharing) system for local community bodies

2) Heat control

2030: Establishment of technological basis for exhaust heat ≈ 0 processes

2040: Deployment of exhaust heat ≈ 0 processes to various industries, and pilot-scale demonstration and test operation

2050: Realization of exhaust heat ≈ 0 industry by industrial–consumer sector coupling and introduction of exhaust heat ≈ 0 processes

3) Heat transport

2030: Demonstration of an offline heat transport system with automatic operations

2040: Widespread use of an offline heat transport system with automatic operations

2050: Widespread use of a heat transport system integrated with logistics and public services

4) Heat recuperation and circulation

2030: Development and proof-of-concept of energy regeneration processes compatible with various temperature ranges

2040: Completion of pilot-scale demonstration tests

2050: Realization of an energy society with minimal energy consumption through widespread use of energy regeneration processes

5) Social/Information systems

2030: Operation of local currency technology for local energy (electricity) and launch of local community bodies (trial operation)

2040: Operation of local currency technology for local energy (electricity + heat) and launch of local community bodies (trial operation)

2050: Operation of integrated exchange and circulation systems for all forms of value (intra-regional logistics, energy, and services)

Table III-1 Targets (milestones) for 2030, 2040, and 2050

Item	2030	2040	2050
1) Energy storage	Demonstration of a thermal storage system in a demonstration plant as an energy storage system (test operation)	Widespread use of thermal storage systems as energy storage systems and expansion of sector coupling	Realization of an energy circulation (energy sharing) system for local communities
2) Heat control	Establishment of technological basis for exhaust heat ≈ 0 processes	Deployment of exhaust heat ≈ 0 processes to various industries, and pilot-scale demonstration and test operation	Realization of exhaust heat ≈ 0 industry by industrial–consumer sector coupling and introduction of exhaust heat ≈ 0 processes
3) Heat transport	Demonstration of offline heat transport systems with automatic operations	Widespread use of offline heat transport systems with automatic operations	Widespread use of heat transport systems integrated with logistics and public services
4) Heat recuperation and circulation	Development and proof-of-concept of exergy regeneration processes compatible with various temperature ranges	Completion of pilot-scale demonstration tests	Realization of an energy society with minimal energy consumption through widespread use of exergy regeneration processes
5) Social/Information systems	Operation of local currency technology for local energy (electricity) and launch of local community bodies (trial operation)	Operation of local currency technology for local energy (electricity + heat) and launch of local community bodies	Operation of integrated exchange and circulation systems for all forms of value (intra-regional logistics, energy, and services)

②Specific R&D themes to be addressed to achieve the proposed milestones

1) Energy storage

1-1 2030 Milestone: *Demonstration of a thermal storage system in a demonstration plant as an energy storage system (test operation*)

- ➢ Development of inexpensive and high-performance heat storage materials and their mass production technology
- ➢ Development of heat storage and exchange systems by combining high heat storage density and fast heat exchange performance
- ➢ Development of high-efficiency electric heat conversion technology

- Demonstration test by small-scale installation and operation of a demonstration plant

1-2 2040 Milestone: *Widespread use of thermal storage systems as energy storage systems and expansion of sector coupling*

- Scale-up of heat storage and exchange systems by combining high heat storage density and fast heat exchange performance
- *Demonstration test of electric heat cogeneration in a thermal storage system as an energy storage system*

1-3 2050 Milestone: Realization of an energy circulation (energy sharing) system for local community bodies

- Development of an intraregional heat and electricity operation system associated with social and information system technologies

2) Heat control

2-1 2030 Milestone: Establishment of technological basis for exhaust heat ≈ 0 processes

- Development of thermal control technology using coproduction-type endothermic phenomena, such as chemical reactions
- Development of controlled cooling technologies with heat recovery from solid sensible heat
- Development of exergy loss minimization heat recovery and utilization technologies using dirty waste heat sources

2-2 2040 Milestone: Deployment of exhaust heat ≈ 0 processes to various industries, and pilot-scale demonstration and test operation

- Pilot-scale demonstration test of exhaust heat ≈ 0 process suitable for various industries

2-3 2050 Milestone: Realization of exhaust heat ≈ 0 industry by industrial–consumer sector coupling and introduction of exhaust heat ≈ 0 processes

- Optimization of the entire system according to the characteristics of various industries and regions

3) Heat transportation technology

3-1 2030 Milestone: Demonstration of offline heat transport systems with automatic operation

- Development of heat storage materials and devices that can store and transport at room temperature and with fast heat output
- Development of fully automatized offline heat transport and utilization technologies

3-2 2040 Milestone: Widespread use of offline heat transport system with automatic operation

- Demonstration test in each municipality

3-3 2050 Milestone: Widespread use of heat transport systems integrated with logistics and public services

- Operational test of offline heat transport systems integrated with value integration and exchange circulation systems

4) Heat recuperating and circulation technology

4-1 2030 Milestone: Development and proof-of-concept of exergy recuperating processes compatible with various temperature ranges

- Development of high-density heat circulation media/processes
- Development of thermal upgrading methods (mechanical/chemical, among others)
- Development of high-efficiency heat exchangers that surpass conventional performance levels and investigation of their integration into various processes

4-2 2040 Milestone: Completion of pilot-scale demonstration tests

- Pilot-scale demonstration tests

4-3 2050 Milestone: Realization of an energy society with minimal energy consumption through widespread use of exergy recuperating processes

- Identification of issues on the implementation path and examination of measures to address them

5) Social/Information systems

5-1 2030 Milestone: Operation of local currency technology for local energy (electricity) and launch of local community bodies (trial operation)

- Positioning and conceptualization of renewable energy as shared social capital
- Design of value exchange systems for the use of renewable energy (economic, legal, and institutional)
- Value exchange technology system based on blockchain technology, among others.
- Development and demonstration of nudge technology to promote civic behavior change (design, art, among other approaches)
- Test launch of local community body (citizen-funded joint ventures)

5-2 2040 Milestone: Operation of local currency technology for local energy (electricity + heat) and launch of local community bodies

- Development of energy traceability and tagging technologies
- Design of value exchange systems for logistics and services other than energy

(economic, legal, and institutional)

- Consideration of evolvable systems and business structures that meet the current demands
- Organization of new citizen roles and responsibilities, and creation of mechanisms to encourage social participation (self-governance, consensus building, education, among others)

5-3 2050 Milestone: Operation of integrated exchange and circulation systems for all forms of value (intra-regional logistics, energy, and services)

- Development of integrated exchange and circulation systems for all forms of value (intra-regional logistics, energy, and services)
  (linked with other public sectors, such as education, welfare, and regional transport)

Table Ⅲ-2 Specific research and development subjects to be addressed toward achieving the milestones, and effects on society

	2030	2040	2050
1) Energy storage	Demonstration at demonstration plant of heat storage systems as an energy storage system (test operation) - Development of a cheap, but high-performance heat storage system and the construction of a mass-production technology - Development of a heat storage/exchange system equipped with both high heat storage density and high-speed heat exchange performance - Development of a highly-efficient electric heat conversion technology - Demonstration tests with small-scale introduction and operation of a demonstration plant	Dissemination of heat storage system as an energy storage system and expansion of sector coupling - Scaling up of heat storage/exchange systems equipped with high heat storage density and high-speed heat exchange performance - Demonstration tests of combined heat supply in heat storage systems as an energy storage system	Realization of an energy circulation (energy sharing) system in local communities - Development of a regional heat/electricity operation system associated with social/information system technologies
2) Heat control	Construction of a technological foundation with a near-zero exhaust heat process -Development of heat control technologies, such as the coproduction-type heat absorption phenomenon	Development of near-zero exhaust heat processes into various industries and demonstration/test operation at the pilot scale - Demonstration tests	Realization of near-zero exhaust heat industries through industry–consumer sector coupling and introduction of near-zero exhaust heat processes - Overall system

	(such as chemical reactions) - Development of controlled cooling technologies along with heat absorption from solid sensible heat - Development of heat collection/use technologies with minimum exergy loss from dirty heat exhaust sources	of near-zero exhaust heat processes at the pilot scale that are suited for each industry	optimization according to each industry and regional characteristics
3) Heat transportation	Demonstration of offline heat transport systems using automatic operation Development of a heat storage material/device capable of storage/transport at room temperature and high-speed hear output Development of an offline heat transport/technology with complete automatic operational capabilities	Dissemination of offline heat transport systems using automatic operation - Demonstration tests in each municipality	Dissemination of heat transport systems that integrate logistical/public services - Operational tests of offline heat transport systems that are integrated with the implemented value exchange circulation system
4) Heat recuperating	Development and proof-of-concept of an exergy-renewable process that is compatible with various temperature zones - Development of a high-density heat circulation medium/process - Development of a heat upgrade method (such as mechanical/chemical methods) - Development of high-efficiency heat exchange devices that surpass the conventional performance and investigations on the integration of each process	Completion of demonstration tests at the pilot scale - Demonstration tests at the pilot scale	Realization of a society with minimal energy consumption through the dissemination of exergy regeneration processes - Extraction of issues toward implementation and investigation of countermeasures for it
5) Social/information system	Operation of local currency (green currency) technology for local energy (electricity) and launch of local communities (test operation) - Positioning and conceptual arrangement of renewable energy as a common social resource - Value exchange system design for renewable energy use (economy, law, and regulations) Development of value	Operation of local currency technologies for regional energy (electricity + heat) and launch of local communities (test operation) - Energy traceability and tagged technology development - Value exchange system design for logistics/services other than energy (economy,	Integration of all value for regional logistics/energy/services - Development of integrated exchange circulation systems of all value for regional logistics/energy/ services (linkage with other public sectors, such as education, welfare, and regional transport)

	exchange technology systems with block-chain technologies, among others. - Development and demonstration of nudge technologies that promote community behavior changes (such as design and art) - Test launch of local communities (citizen-funded community projects)	law, and regulations) - Investigating evolutionary regulatory/project forms that are appropriate for the current setting - Creating mechanisms that organize the new roles and responsibilities of citizens and promote social participation (such as autonomy, consensus-building, and education)	
Effects on society	Society is notified of energy storage technologies with future applicability - Demonstration plant is introduced in a district heating region as a heat storage technology, and surplus renewable energy collection and use is started - Shift to the development of technologies with heat control that do not exhaust heat - Introduction of heat transport using automatic operation - Paradigm shift from energy cascade utilization to exergy regeneration - Regional renewable energy becomes common, and operational tests of regional currency (green currency) by local communities are initiated	Application of energy storage technologies begins in various fields - Advances in the formation district heating microgrids that use energy storage technologies, as well as the realization of sector coupling due to heat storage technologies by industry and consumer sectors - Demonstration of thermal control technology extended to the chemical and steel industries - Municipalities that introduce heat transport technologies increase, and energy lending between municipalities commences - Pilot scale demonstration tests of renewable heat technologies - Trades between local communities over heat as well as electricity begin with local currencies	Operation of integrated exchange circulation systems of all value for regional logistics/energy/services - Dissemination of heat circulation technologies of energy storage, heat control, heat transport, and heat regeneration - Overall optimization by lending of electricity/heat through advances in sector coupling and demand-response, as well as next-generation EMS - Advances are made in value integration with other public sectors (such as education, welfare, and regional transport) and energy, trading with regional currencies ramps up, and economic circulation within a region is established - 2050 is recognized as the first year of the formation of an independent and distributed network society

③ Effects on society by attaining milestones

2030: The society is notified of energy storage technologies with future applicability

1）Demonstration plant is introduced in a district heating region as a heat storage technology, and surplus renewable energy collection and use is initiated.

The development of each element necessary for establishment of the system has been achieved, and demonstration tests by introducing and operating the demonstration plant are started. In consideration of future expandability, the demonstration plant is installed in areas where the district heat pipes are laid. For the time being, the demonstration plant is installed and operated as a technology that contributes to the collection of surplus electricity from renewable energy, which has become widespread as well as the stable supply of electricity. The success of this demonstration and operation accelerates the spread of renewable energy introduction as renewable energy, which is an unstable energy source, can be stored at a low cost, and can be operated in a constant manner.

2）Shift to development of technologies with heat control that do not exhaust heat

“Collection of low-temperature waste heat”, which has been the paradigm of waste heat collection technology to date, will shift to the “development of technologies that do not generate waste heat” through proof-of-concept of product waste heat collection technologies.

3）Introduction of hear transport using automatic operation

The aim is to not only to disseminate autonomous driving but also to reduce running costs = labor costs, which has been an issue for hear transport to date, to pave the way for heat transport technology use as a flexible energy operation.

4）Paradigm shift from energy cascade utilization to exergy recuperating

A proof-of-concept of exergy recuperating technology in all temperature zones and a high-performance heat exchange device for achieving this technology in a realistic timeframe scale and cost has been achieved, and the momentum for a paradigm shift from energy cascade utilization to exergy regeneration will increase.

5）Regional renewable energy becomes common and operational tests of regional currency (green currency) by local communities are initiated

Advances are made on discussions regarding the harvesting, storage, and use of renewable energy as a common social capital. Simultaneously, social creditworthiness of regional currencies (green currencies) using virtual currencies has increased, and some regions jointly start operational tests of regional currency for renewable energy-based electricity between regions.

2040: Application of energy storage technologies begins in various fields

1）Advances in the formation of district heating microgrids that use energy storage technologies, as well as the achievement of sector coupling due to heat storage technologies by industry and private sectors

A district heating microgrid starting from the energy storage system is formed with the expansion of the business. A microgrid of energy storage × district heating from renewable energy power sources × heat storage becomes a useful option for redeveloping regional infrastructures. Sector coupling with industry is also attained through heat in some regions. The exhaust heat emitted from industrial processes is collected by the heat storage system, which can be supplied to consumers in the form of heat or electricity. Advances are made in the electrification of industry, and electricity is cheaply purchased and used with demand response. The waste heat generated from this process is stored and supplied to the consumer as heat or electricity.

2）Demonstration of thermal control technology extended to the chemical and steel industries

The demonstration of near-zero waste heat processes is extended primarily to the chemical and steel industries.

3）Municipalities that introduce hear transport technologies increase and energy lending between municipalities commences

Heat transport technologies become widespread in each municipality. Construction of a thermal energy network that transports excess heat within a region to neighboring local governments also begins.

4）Pilot scale demonstration tests of renewable heat technologies

Demonstrations on a pilot scale are developed.

5) Starting transactions in regional currency for heat and electricity through regional

cooperatives

As technology centered on thermal storage becomes more commonplace, local cooperatives will begin transactions for thermal energy and renewable electricity. As sector coupling moves forward, value exchanges will reach beyond regional social welfare sectors toward far-flung industrial fields. In addition, energy lending among adjacent municipalities will increase, and implementation of value exchanges among different regional currencies will begin.

2050 Implementation of integrated exchange circulation of all value in regional logistics, energy, and services

1) Heat circulation technology for energy storage, thermal control, heat transport, and heat regeneration will be optimized overall through electricity and heat flexibility, demand response, and next-generation EMS, made possible through further sector coupling.

2) Value integration between energy and other public sectors (education, welfare, regional transit, etc.) will increase, and transactions in regional currencies will become routine, creating an economic environment within the region.

3) 2050 will be recognized as the inaugural year of forming the independent distributed network society.

3. International Cooperation for Achieving the Goal

HO・DO・HO・DO is not a sensibility unique to the Japanese people. Many other countries and regions value similar ideas, such as “lagom” in Sweden (“not too little, not too much, just the right amount”) and hygge in Denmark (“pleasant atmosphere, pleasant times”). Additionally, in northern Europe, the local heat supply infrastructure using heat pipes and thermal storage facilities using hot water tanks have been widely installed, and research and technological development is being actively conducted to improve the operation and use of these systems. Therefore, discussions will be conducted in partnership with these countries regarding their social systems and technologies for circulating energy through decentralized urban areas on a HO・DO・HO・DO scale.

To achieve the target, while widely spread of renewable energy and power and hydrogen usage is fundamental, supporting that foundation is heat usage technology used for storage, transportation, regeneration and control technology on multiscale. Integration/ fused with social, information and that of technology is essential. Therefore, progressive latent heat storage, chemical heat storage technology and research development for exergy regenerative technology should be promoted as common technical foundation. For the industrial field where large amount of energy is consumed, challenging technical development need to be encouraged to realize heat control, regeneration and circulation use in high temperature region without generating waste heat. The field of Integrated/fused in informational technology and social technology such as fully autonomous driving for heat transportation is needed to advance in the consumer filed where maturing technology in low temperature region is predicted to use. Moreover, development for heat storage technology should be promoted as a robust and seasonal storage technology that become a core of heat regeneration and circulation usage on large scale thorough coupling sectors.

4. How to Collaborate Across Sectors and Filed for Achieving the Goal

To achieve the relevant MS targets, technology development through on-site demonstration must be conducted through partnerships spanning the sectors listed below.

- Core technology development sectors (universities, research institutions, businesses)
- Related technology development sectors (universities, research institutions, relevant businesses)
- Social technology sectors (universities, research institutions)
- Information technology sectors (universities, research institutions, relevant businesses)
- Government sectors (governments, politicians, etc.)

These partnerships must not take the form of closed relationships based on individual connections, such as the conventional researcher-researcher or researcher-business partnerships, but rather a space must be created for open discussion. For example, in the JST "Joint Development Space Creation Support Program" sponsored by MEXT, shared visions are determined through organization- organization cluster partnerships, and structures are created for promoting research on issues set based on backcast-determined targets. It will be vital to open this type of "university space" to diverse stakeholders and create a space where free and open discussion can be held under standard social rules such as protection of confidentiality. It is hoped that in working toward achieving these MS targets, the concept of a joint development space will begin the creation of structures by diverse stakeholders to build relationships and give rise to creative jobs in a free and open atmosphere.

In contrast, while development of core technology will be conducted in an intellectual property closed environment through government project acquisition and joint development with businesses, thorough information will be distributed about fields where the technology can be applied. Intellectual property will be protected, and strategies for involving the aforementioned joint development spaces will be continuously considered to promote upward spiraling into technology development and on-site demonstration of societal implementation (social experimenting).

From here, partnerships with other teams formed through this millennium program will be strengthened. Regular information exchange will form a basis for joint symposiums, seminars, and workshops, to build relationships, and lead to more effort being placed in human resource development involving undergraduate students, graduate students, doctoral students, adult students, and young researchers to form strong networks that can generate continuous innovation. In addition, it will be necessary not only to publish the research results in academic journals, but also to create systems for widely conveying to citizens the necessity, evolution, and possibilities of the research. To reach many different generations, information effects and information gathering mechanisms will be developed using various forms of media, which will function as spaces for the information and communication necessary for consensus building, during which research, development, and demonstration will be continuously conducted.

How will we create the post-SDGs world? Debate and communication across sectors should form the basis for creating systems prepared to overcome future issues.

5. ELSI (Ethical, Legal, Social Issues)

1) Handling of Societal Issues Such as Personal Information Management

First, it will be necessary to proceed with research and development in accordance with the fast pace of changes in ethical values and rules (domestic, international) while being attentive to global and domestic debates.

2) Consensus Building and Communication

Regardless of the quality of technology and systems, consensus building is vital for societal implementation of these systems. Achieving this goal requires communication with a wide variety of stakeholders. To propel this research, the regional demonstration step is necessary so that from the demonstration study stage, researchers visit each region to share future visions and targets and conduct research that reflects the opinions and perspectives of local residents. As described above, managing personal information remains difficult, but the project will be conducted by forming cooperative organizations with local residents to gain their trust and then proceed reliably step by step.

IV. Conclusion

1) The process of this project

The following figure Ⅳ-1 illustrates plan for this project and the table Ⅳ-1 shows actual process. In totally seven times of meeting, members of team brought some topics, external lecturers provided topics and instructors joined discussion for this project. Moreover, in order to collect opinions from diverse generations such as students and young researchers, we hold a workshop called DEMOLA program “What is it like to be our world in 2100?” organized by young researchers, post-graduate student, undergraduates from young-workshop and people from cold region workshop.

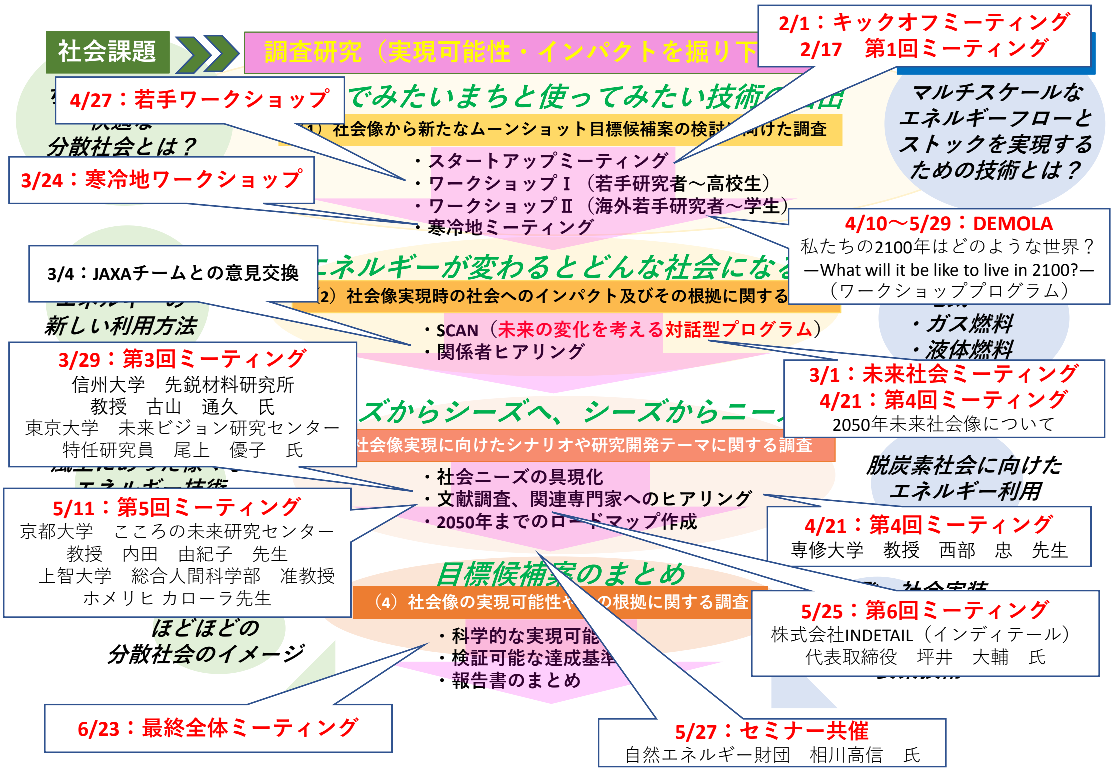


Fig.Ⅳ-1　The plan for this project

Table Ⅳ-1　the process of this project

Day	Contents	Details
1st Feb. 17:30～	First meeting（kick-off Meeting） ➢ How to conduct the survey, assign a role and discuss about contents ➢ Topics 1） Takahiro Nomura ”Topics about heat	Factory of engineering, Academic lounge3

	storage technology" 2) Yutaka Tabe " Futural target for energy system in Hokkaido" 3) Naoyuki Mikami "Citizen's climate conference Sapporo in 2020 ; about citizen conference in Sapporo". 4) Itsuro Sugimura (Institute for the promotion of business-regional collaboration) "Explanation about DEMOLA". 5) Kazuei Ishi "Orientation report". ➢ Introduction of message from Dr. Kuno's virtual laboratory	
17th Feb. 17:30〜	Second meeting ➢ Topics 1) Takahiro Nomura ,"Vision for implementing h-MEPCM ,innovative storage thermal materials." 2) Motoko Okumoto ,"Sustainable futural image for high school student through STEAM approach" ➢ How to proceed the study of social image in future and DEMOLA ➢ About Workshop ➢ About meeting with external experts (request about lecture) ○Free discussion	Factory of engineering, Academic lounge3
1st Mar.	Exchange opinions about future image in 2050.	Academic lounge3
5th Mar.	Exchange opinions with members of Other teams	WEB opening
24th Mar.	Cold region workshop ➢ Twenty of undergraduates from other fields and other majors are joined. ➢ Nineteenth of futural ideas and correspondence analysis for future in cold	WEB opening

	regions which should be achieved in 2050. ➢ Associating futural idea in 2050 and energy fields. ➢ Subject analysis for achievement.	
29th Mar.	Third meeting ➢ Lecture ➢ Report activities and status of planning implementation	Factory of engineering, Academic lounge3
10th Apr.	DEMOLA Program " What is it like to be our world in 2100?" ~ 30th Jun.	
21st Apr.	Fourth meeting ➢ Mr. Shou Takauchi, SBI inc. Facilitator "About futural and social image in 2050" ➢ How to proceed the report ➢ Takahiro Nomura" Future opened by thermal usage." ➢ Exchange opinions about future image. ➢ Mr. Makoto Nishibe, Senshu University, Professor, "A life with regional currency" ➢ Contents of discussion	Factory of engineering, Academic lounge3
27th Apr. 10:00～12:00	A workshop by young researcher, postgraduates and undergraduates. Total number of participants is 16, ranging from younger employee from companies, Postdoctoral students, postgraduates and undergraduates. ➢ Brainstorming about "idea of heat usage". ➢ Sharing idea that heat is added value and transported internationally, brand heat, labeled heat, use for entertainment.	WEB opening
11th May. 13:00～16:00	Fifth meeting ➢ Lectures about Happiness	WEB opening

	➢ About the report(free discussion) ➢ About wellbeing ➢ About HO・DO・HO・DO	
25th May. 16:00～	Six meeting ➢ Lecture about Block chain ・ Mr. Daisuke Tsuboi, INDETAIL Co., Ltd. A representative director "Block chain and energy" ➢ About interim report meeting	WEB opening
26th May.	➢ Hearing: Foreign company	WEB opening
27th May. 13:00～15:00	Co-hosted seminar with Japan Society of Material cycles and Waste Management Topics: The role of Biomass and waste for carbon-free society in terms of energy aspects. 1. Mr. Takanobu Aikawa, Renewable Energy Institute "A role of biomass economy for carbon free society in 2050: From an aspect of synergistic effect of natural energy 2. Ms. Izumi Tanaka, Embassy of Denmark "A role of biomass and waste; Actions for carbon free society and 100% renewable energy use in Denmark." 3. Mr. Naohiro Nakatani, Hitachi Zosen Co. Environmental business development division center " Introduction of case studies about Methanation Technology in Hitachi Zosen co." 4. Roundtable with lecturers Coordinator ： Kazuei Ishi, Hokkaido University, Chairman of the department	WEB opening
29th May.	DEMOLA recital	WEB opening

	・Seven participants; e.g. undergraduates, international students, some working members of society. ・Thema "What is like our world in 2100" ・10th Apr.～Discussion started ・Idea about energy usage E.g., YUKIDENKI, Typhoon Catcher, Thunder tracking	
23rd Jun. 9:00～12:00	Seventh meeting ➢ About the draft	Factory of engineering, Academic lounge3
30th Jun.	DEMOLA Final meeting	Factory of engineering, Academic lounge2

2）**Reformation of members**

Six members below are joined in this project after the initial application (Fig. Ⅳ-2)

- Kayoko Yamamoto（The university of electro-communications, Professor）
- Makoto Nishibe(Shenshu University, professor）
- Chisato Yatabe (National Agriculture and Food Research Organization)
- Teruhiro Satake (Sapporo City Bureau of Environment, Environmental City Promotion Department, Environment Planning Division)
- Makoto Douyashiki (Hokkaido Ishikari City, Planning and Economics Department, Promoting Business Cooperation Division)
- Toshio Yamamoto (Hokkaido Shimokawa Town, Forest Merchants Promoting Division, Industrial Strategy, Biomass Office)

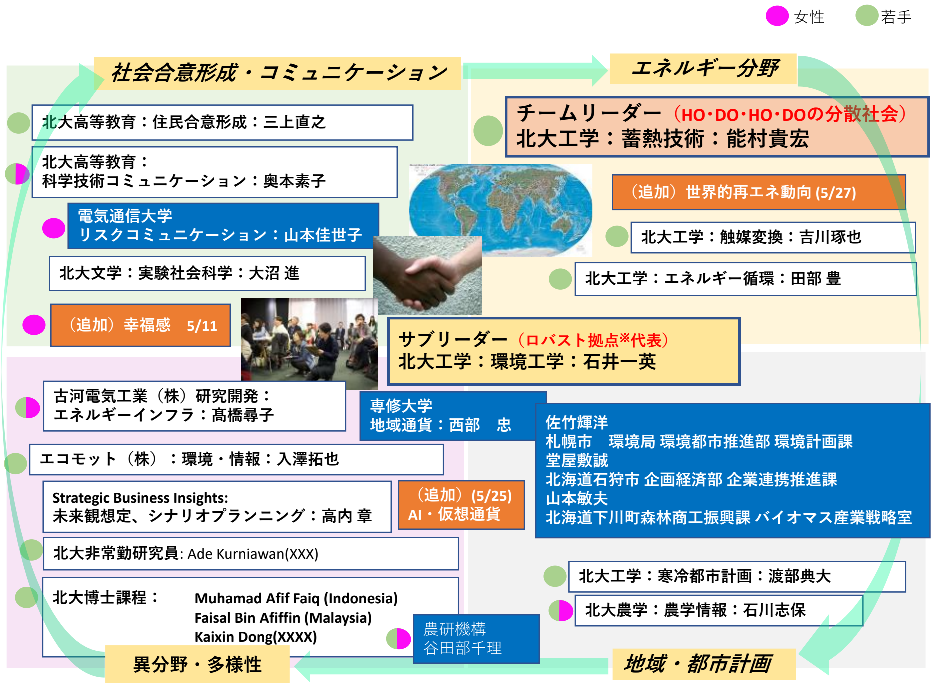


Fig.IV-2　Team member（New members are in blue rectangles）

3) Conclusions

As a conclusion to this report, the Inspiring, Imaginative, and Credible aspects of this proposal are summarized below.

I. Inspiring

・A route towards alleviating and solving the current global environment, infectious disease, and community problems is necessary.

・The current world of material wealth acquired through overuse of resources is not necessarily linked to well-being. Now more than ever, Japanese people are individually reconnecting with their characteristic sensibility HO・DO・HO・DO and spreading information necessary to attain global sympathy.

・The vision of being “free from energy by 2050” does not mean a world in which anyone can use as much sustainable energy as they please, but a world in which we harvest the energy from nature necessary to power our world and then make maximally efficient use of this energy through storage, transport, and sharing.

・Regional sustainable energy is combined with the region-specific value spaces of regional economies, education, welfare, mutual aid, and altruism to achieve a society where many types of goods, energy, and services can be expressed and converted—that is to say, to form a HO・DO・HO・DO independent distributed network society that was not previously achievable.

・Accomplishing this aim will require engineering as well as joint development among diverse sectors, such as humanities and sociological fields, governments, and businesses.

II. Imaginative

・The core technology in this proposal aims to achieve ultimate thermodynamic efficiency through breakthroughs in heat storage technology.

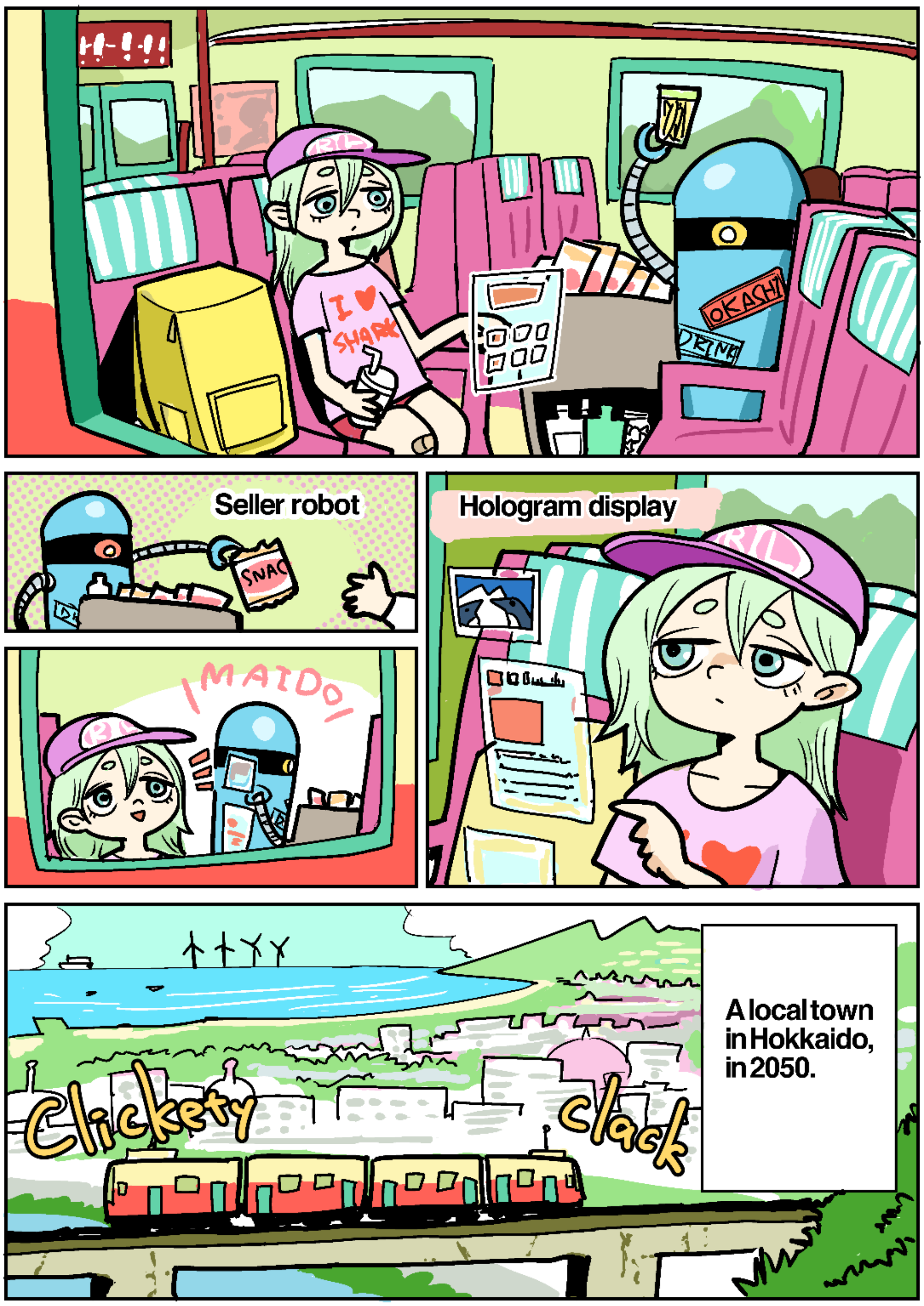
・The ability to freely thermally store, reserve, and transport thermal energy from many different temperature zones and then convert it into electricity or energy in the necessary temperature zones for various uses would enable explosive innovation in a wide range of industrial, public welfare, and transportation fields.

III. Credible

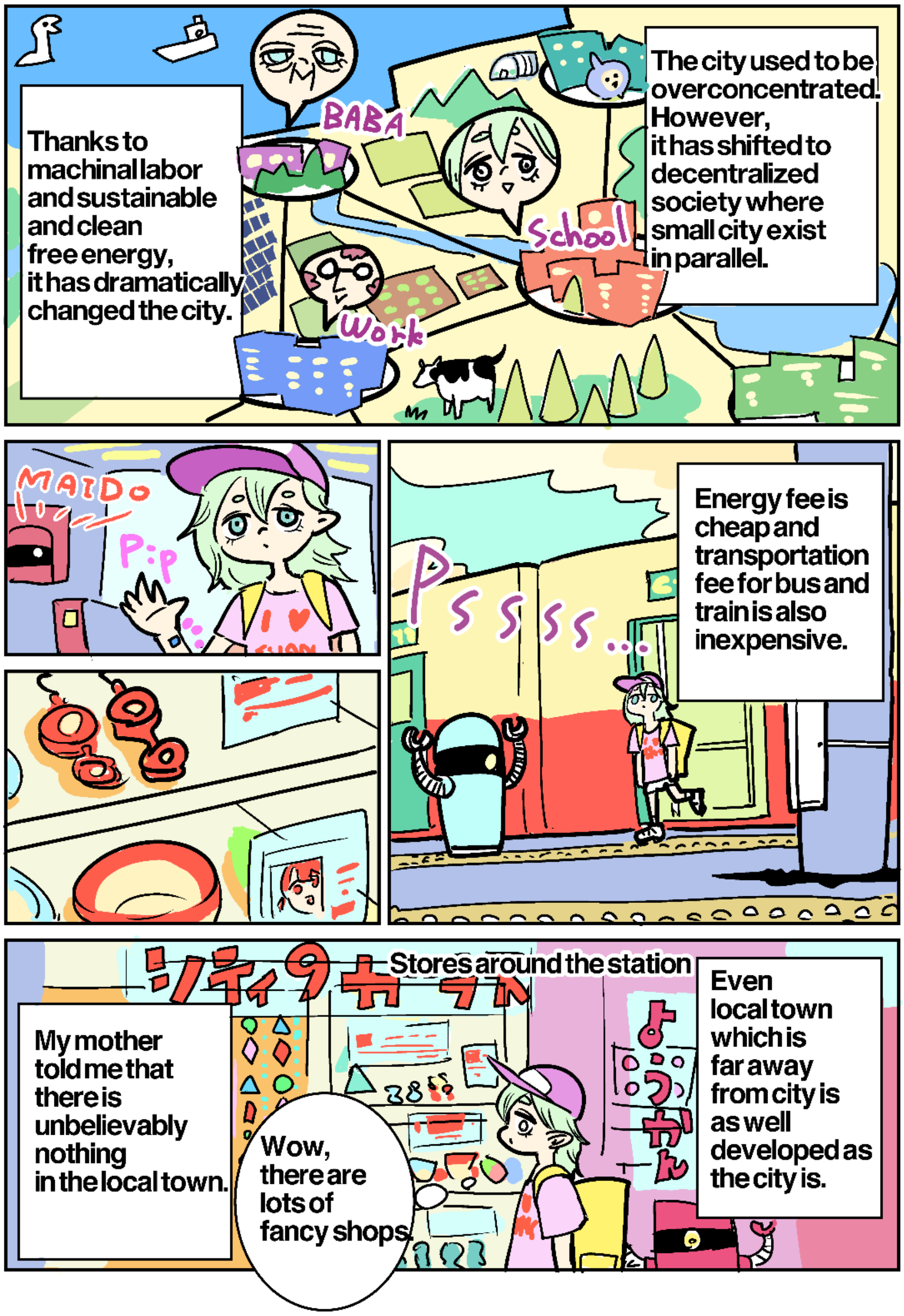
・Revolutionary development of heat storage materials will give rise to the development of new technological systems in the fields of energy storage, thermal control, heat transport, and heat regeneration, causing an about-face in technical systems for various industrial, public welfare, and transportation fields that relied on electricity, power lines, coal, and oil.

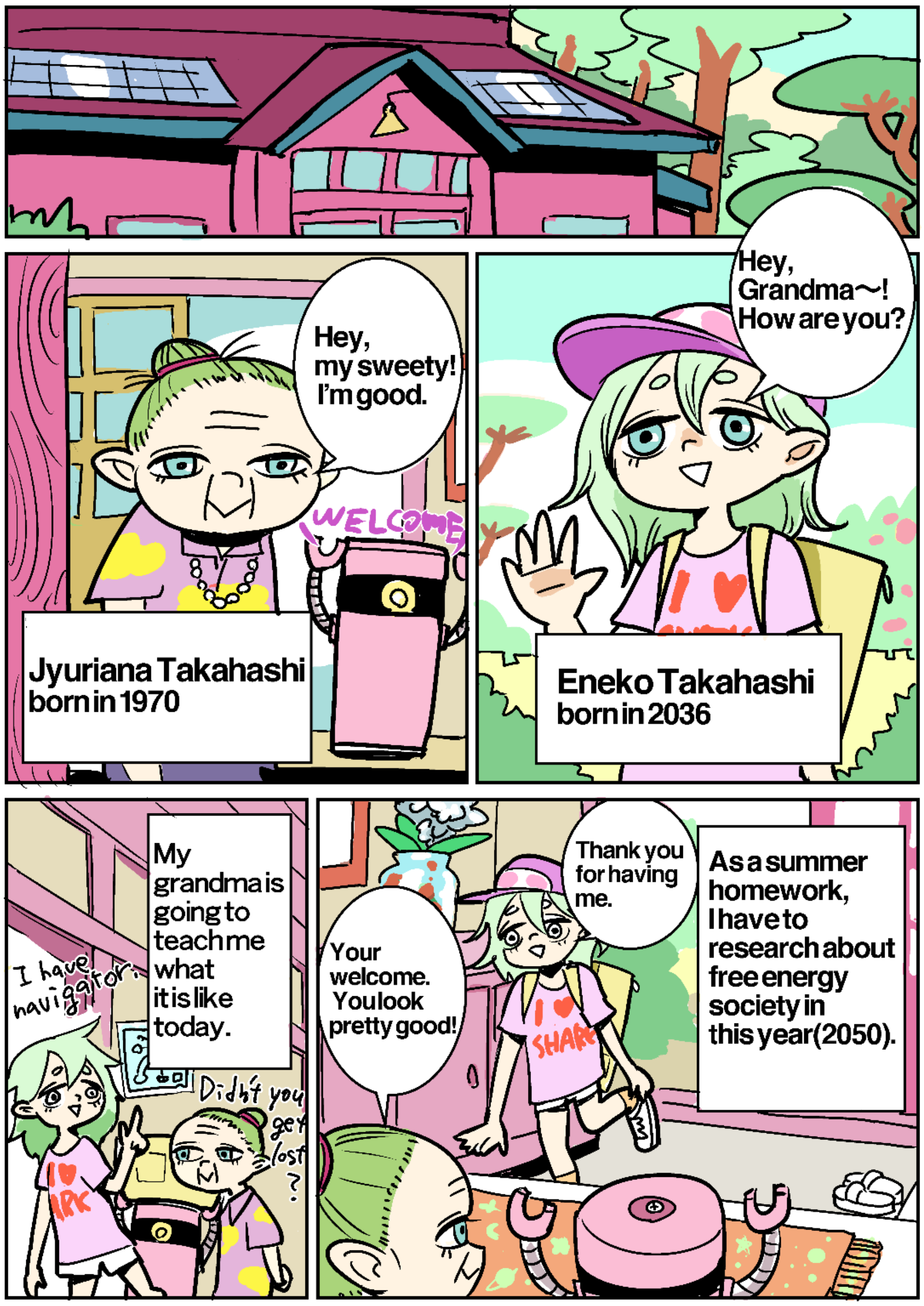
・The proposed goal is that by 2050, only 50% of the current volume of energy will be required, and all of this energy will be covered by renewable energy sources. This conforms with government and global policies aiming for carbon neutrality by 2050.

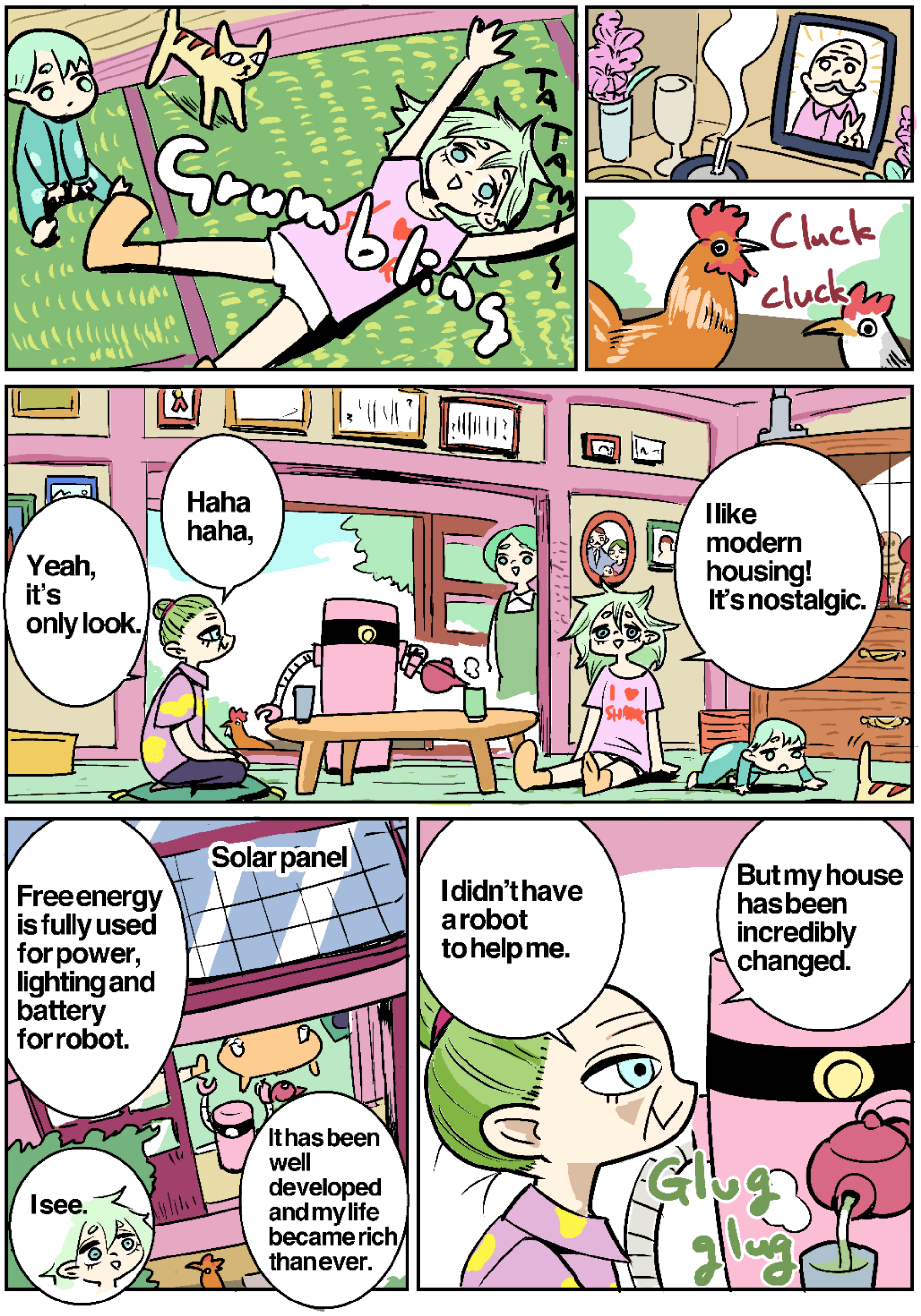
4) Conceptual MANGA of this target proposal for MS

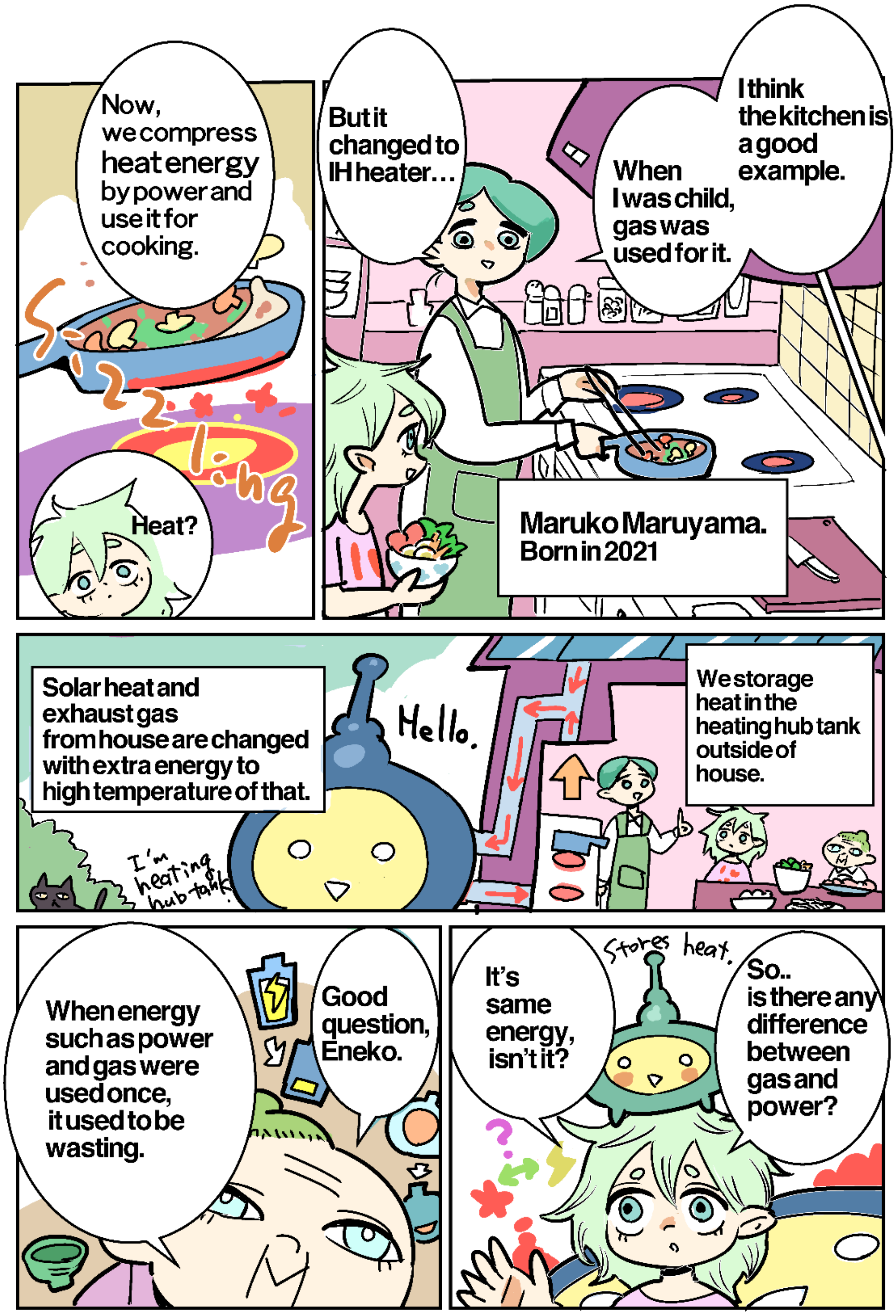


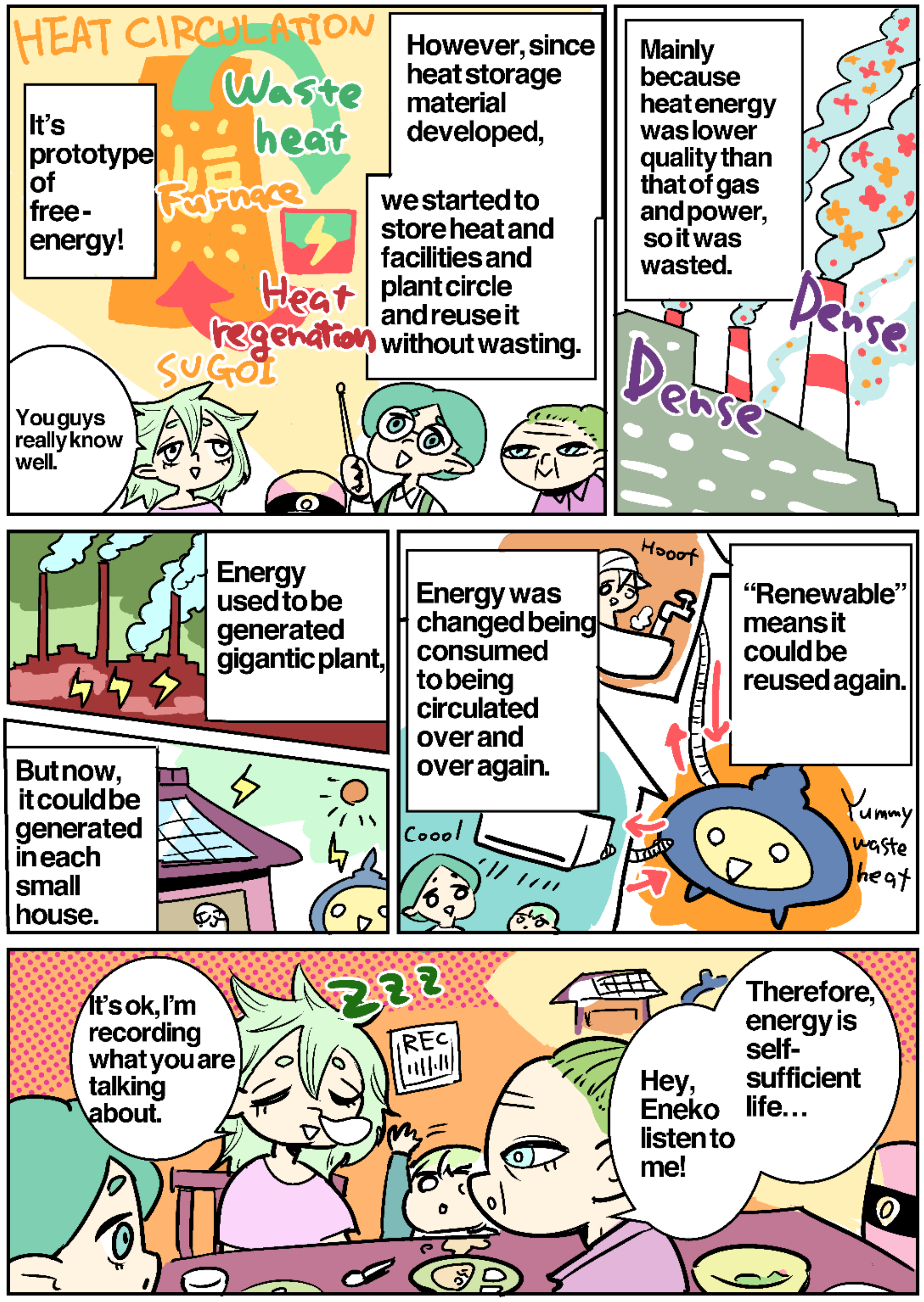
I ♥ SHARK
OKASHI
Seller robot
SNAC
Hologram display
MAIDO
Clickety
clack
A local town in Hokkaido, in 2050.


Thanks to machinal labor and sustainable and clean free energy, it has dramatically changed the city.
The city used to be overconcentrated. However, it has shifted to decentralized society where small city exist in parallel.
BABA
School
Work
MAIDO
P:p
Psss...
Energy fee is cheap and transportation fee for bus and train is also inexpensive.
Stores around the station
My mother told me that there is unbelievably nothing in the local town.
Wow, there are lots of fancy shops.
Even local town which is far away from city is as well developed as the city is.
ようかん

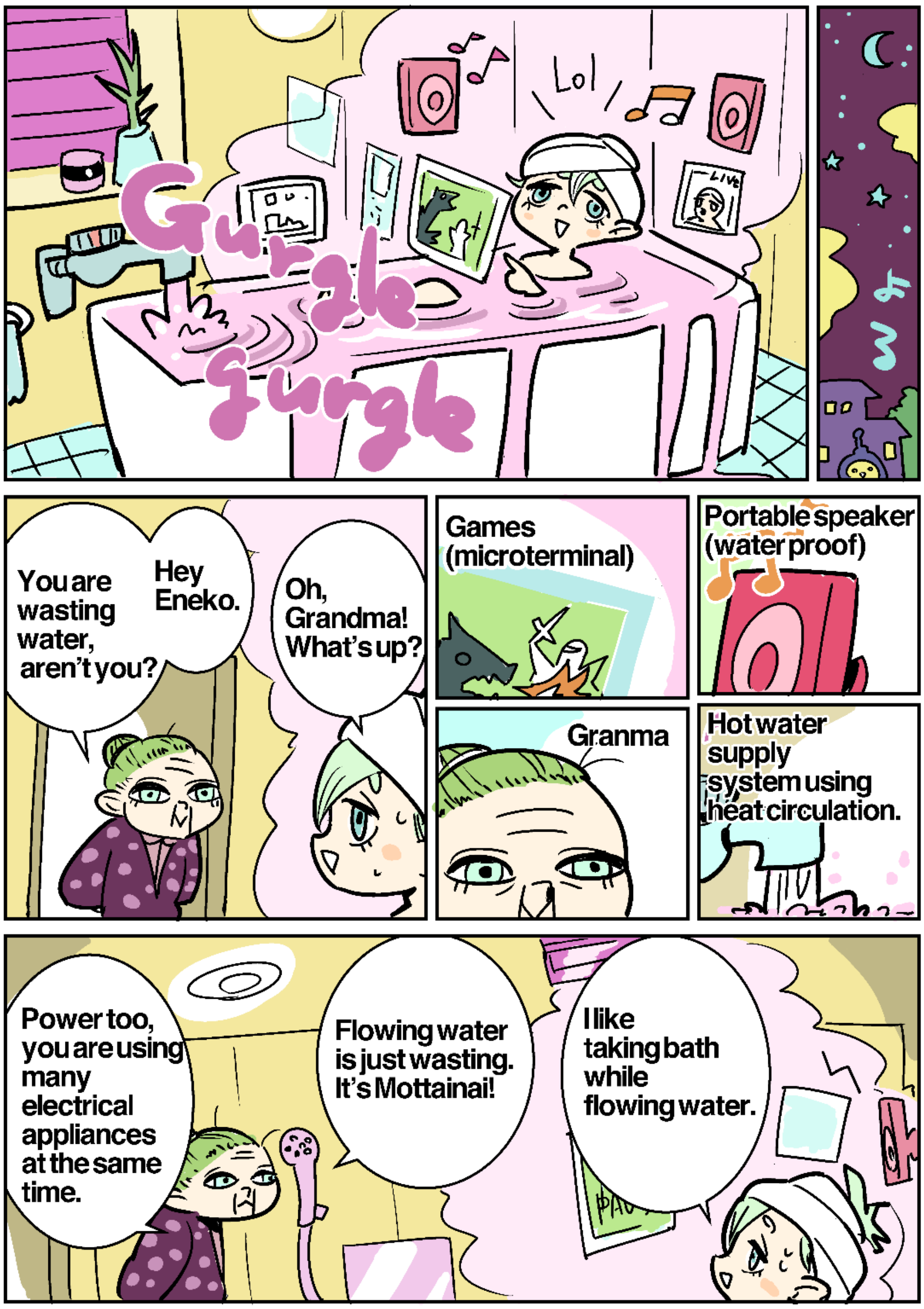

Hey, my sweety! I'm good.
WELCOME
Jyuriana Takahashi born in 1970
Hey, Grandma〜! How are you?
Eneko Takahashi born in 2036
My grandma is going to teach me what it is like today.
I have naviggator.
Didn't you get lost ?
Thank you for having me.
Your welcome. You look pretty good!
As a summer homework, I have to research about free energy society in this year(2050).


Grumblings
TATAMIS
Cluck
cluck
Yeah, it's only look.
Haha haha,
I like modern housing! It's nostalgic.
Solar panel
Free energy is fully used for power, lighting and battery for robot.
It has been well developed and my life became rich than ever.
I see.
I didn't have a robot to help me.
But my house has been incredibly changed.
Glug glug

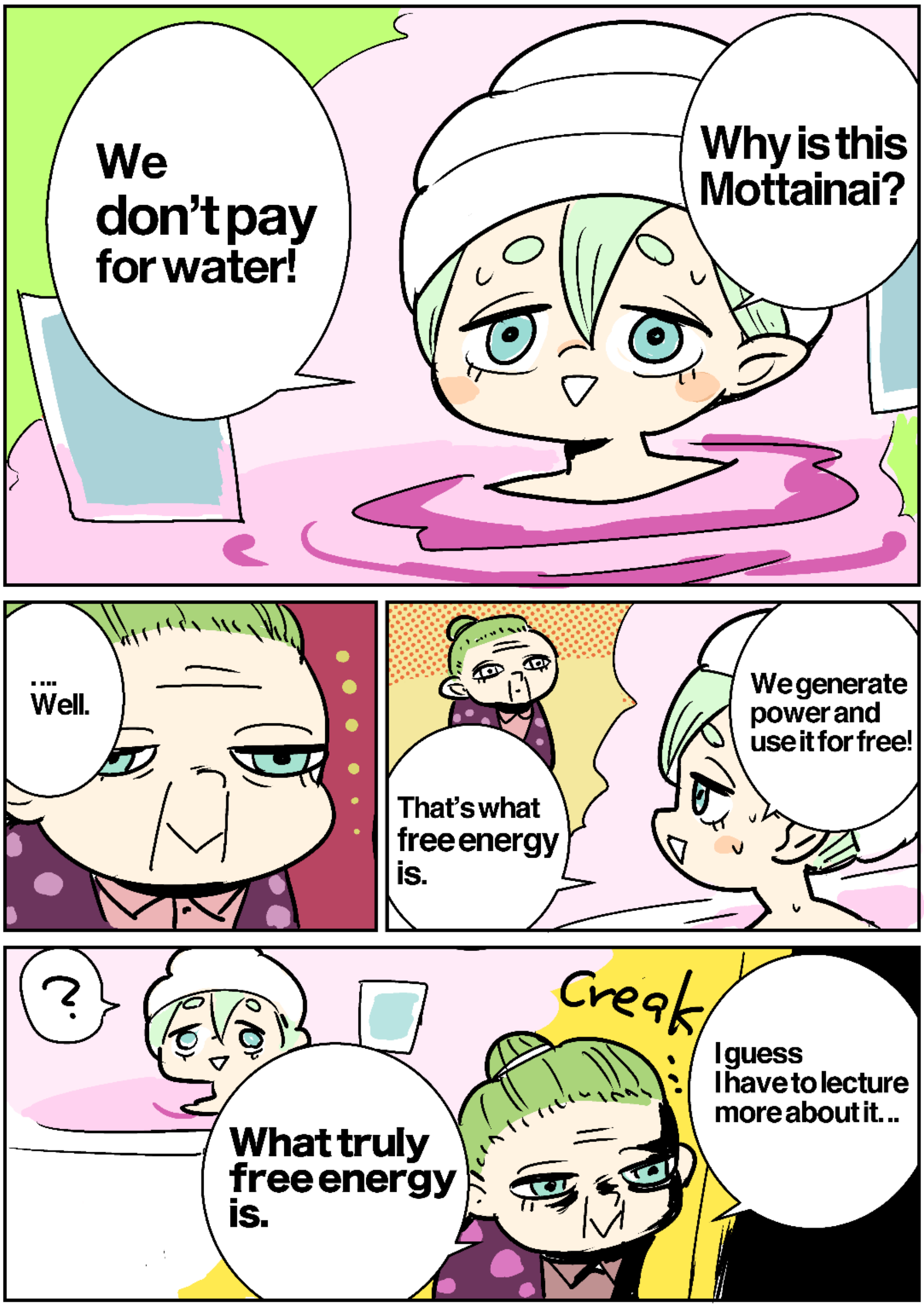

Now, we compress heat energy by power and use it for cooking.
Sizzling
Heat?
But it changed to IH heater…
I think the kitchen is a good example.
When I was child, gas was used for it.
Maruko Maruyama. Born in 2021
Solar heat and exhaust gas from house are changed with extra energy to high temperature of that.
I'm heating hub tank
Hello.
We storage heat in the heating hub tank outside of house.
When energy such as power and gas were used once, it used to be wasting.
Good question, Eneko.
Stores heat.
So.. is there any difference between gas and power?
It's same energy, isn't it?



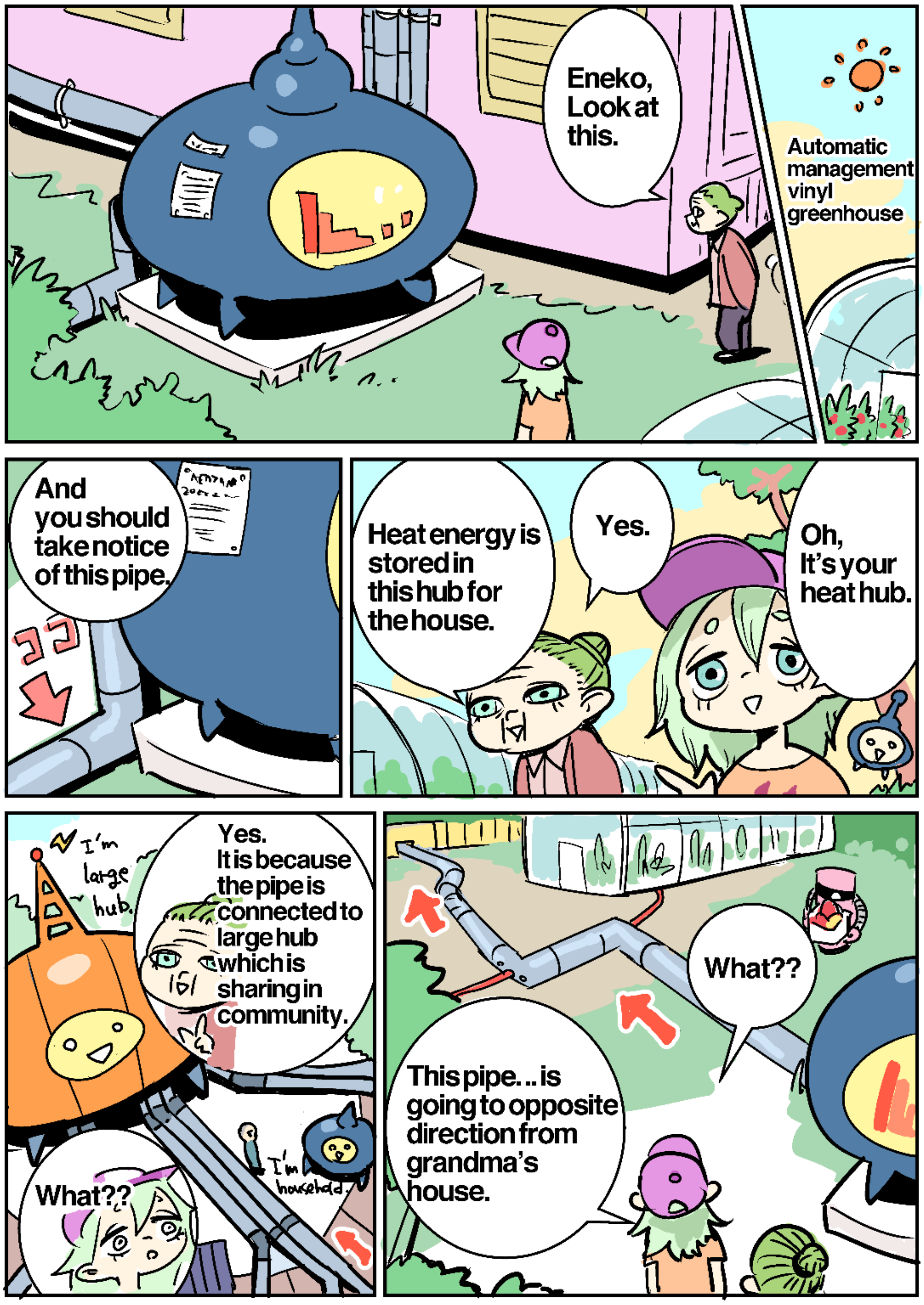
HEAT CIRCULATION
It's prototype of free-energy!
Waste heat
Furnace
Heat regenation
SUGOI
However, since heat storage material developed,
we started to store heat and facilities and plant circle and reuse it without wasting.
You guys really know well.
Mainly because heat energy was lower quality than that of gas and power, so it was wasted.
Dense
Dense
Energy used to be generated gigantic plant,
But now, it could be generated in each small house.
Energy was changed being consumed to being circulated over and over again.
Hooof
"Renewable" means it could be reused again.
Cool
Yummy waste heat
It's ok, I'm recording what you are talking about.
Zzz
REC
Hey, Eneko listen to me!
Therefore, energy is self-sufficient life...

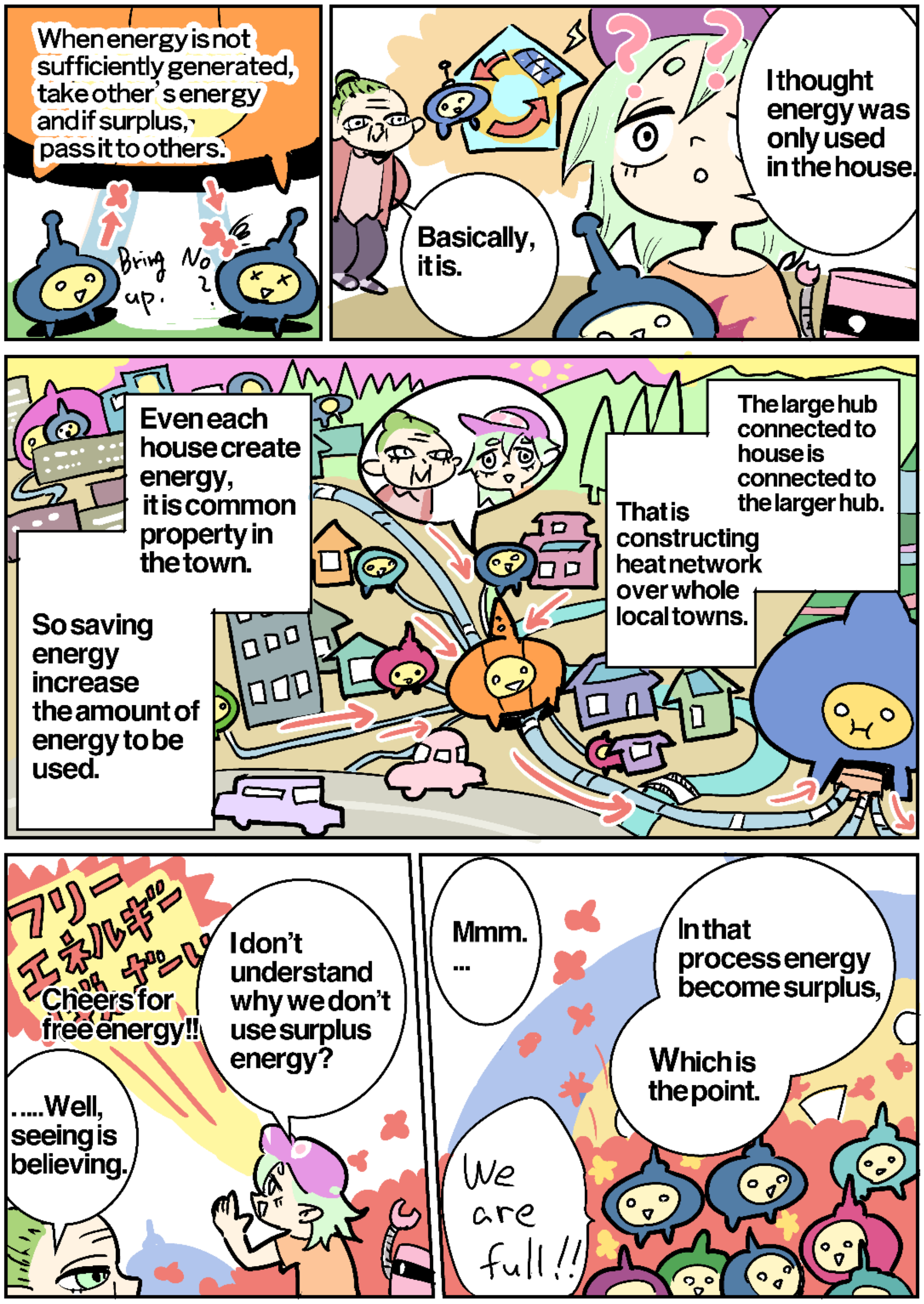


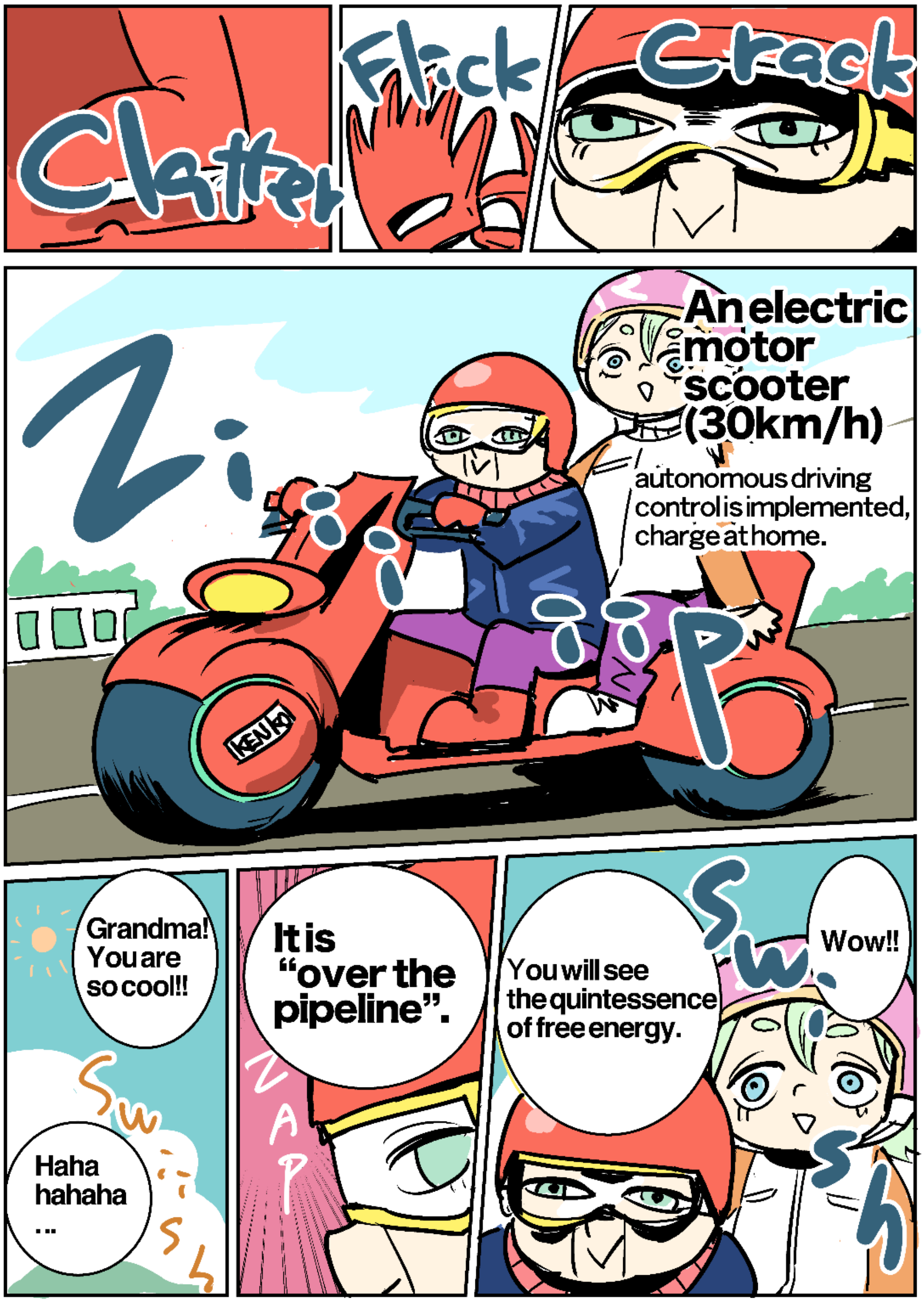
Gurgle
Gurgle
Lol
Hey Eneko.
You are wasting water, aren't you?
Oh, Grandma! What's up?
Games (microterminal)
Portable speaker (water proof)
Granma
Hot water supply system using heat circulation.
Power too, you are using many electrical appliances at the same time.
Flowing water is just wasting. It's Mottainai!
I like taking bath while flowing water.

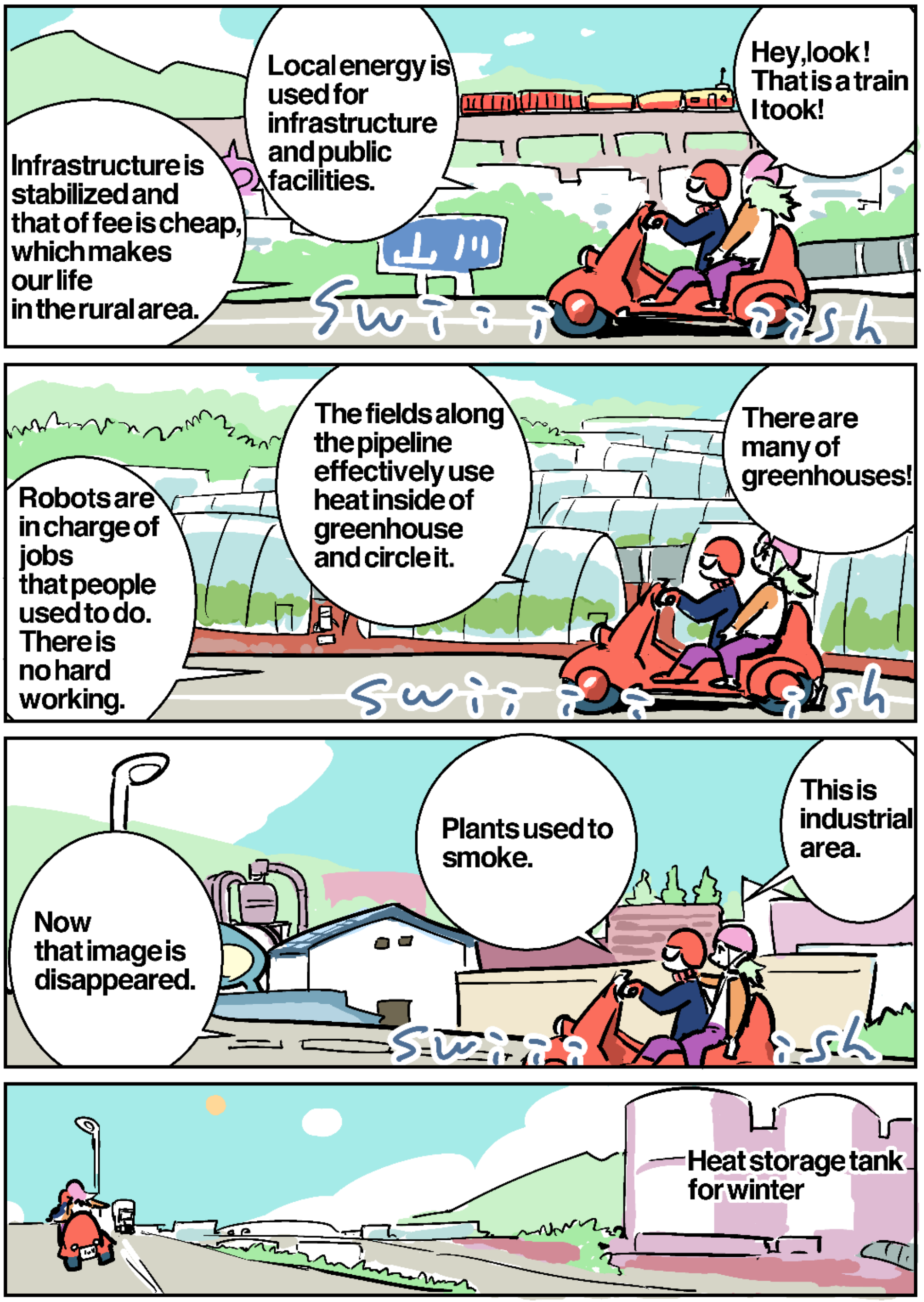


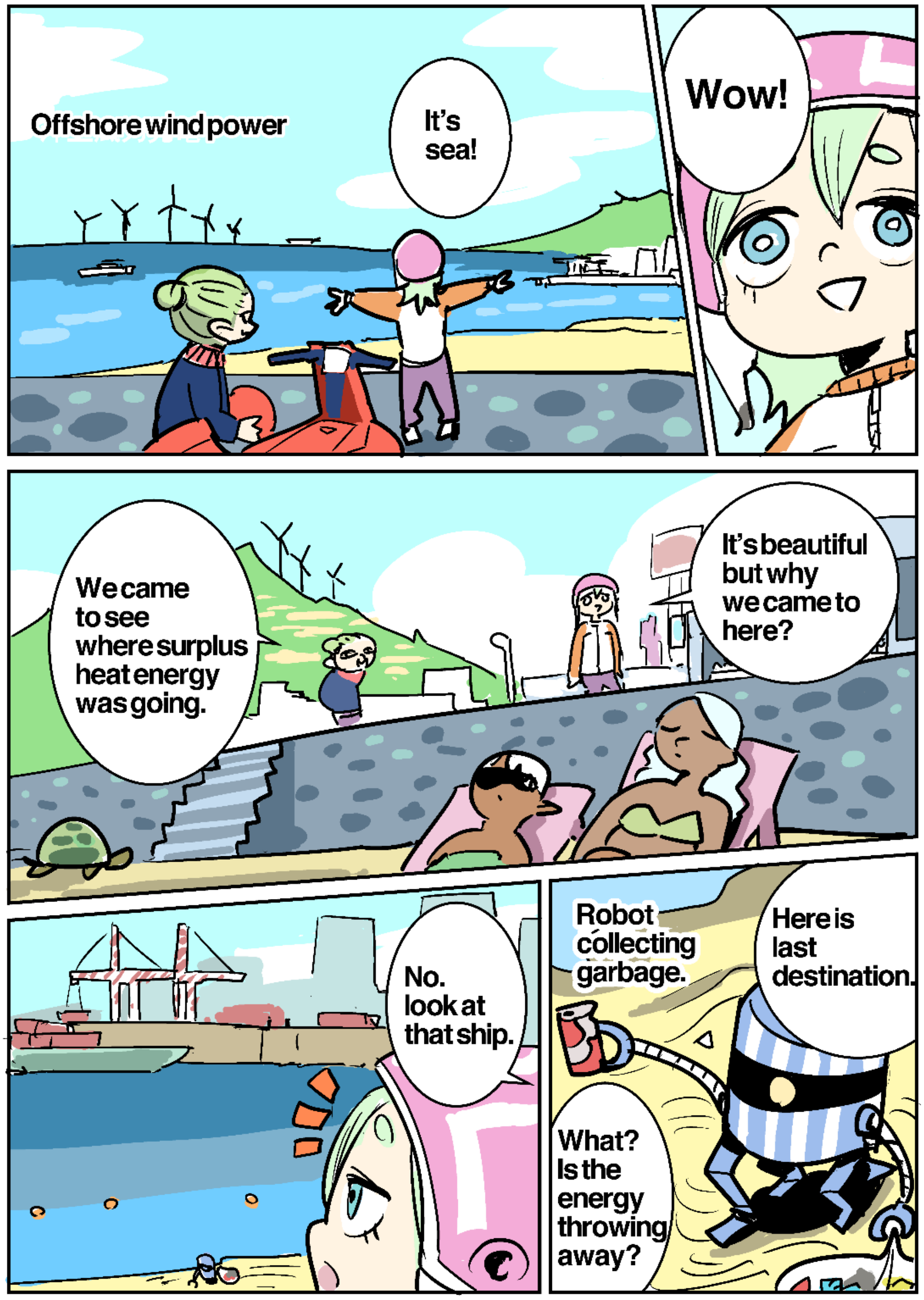
We don't pay for water!
Why is this Mottainai?
.... Well.
That's what free energy is.
We generate power and use it for free!
?
What truly free energy is.
Creak
I guess I have to lecture more about it...

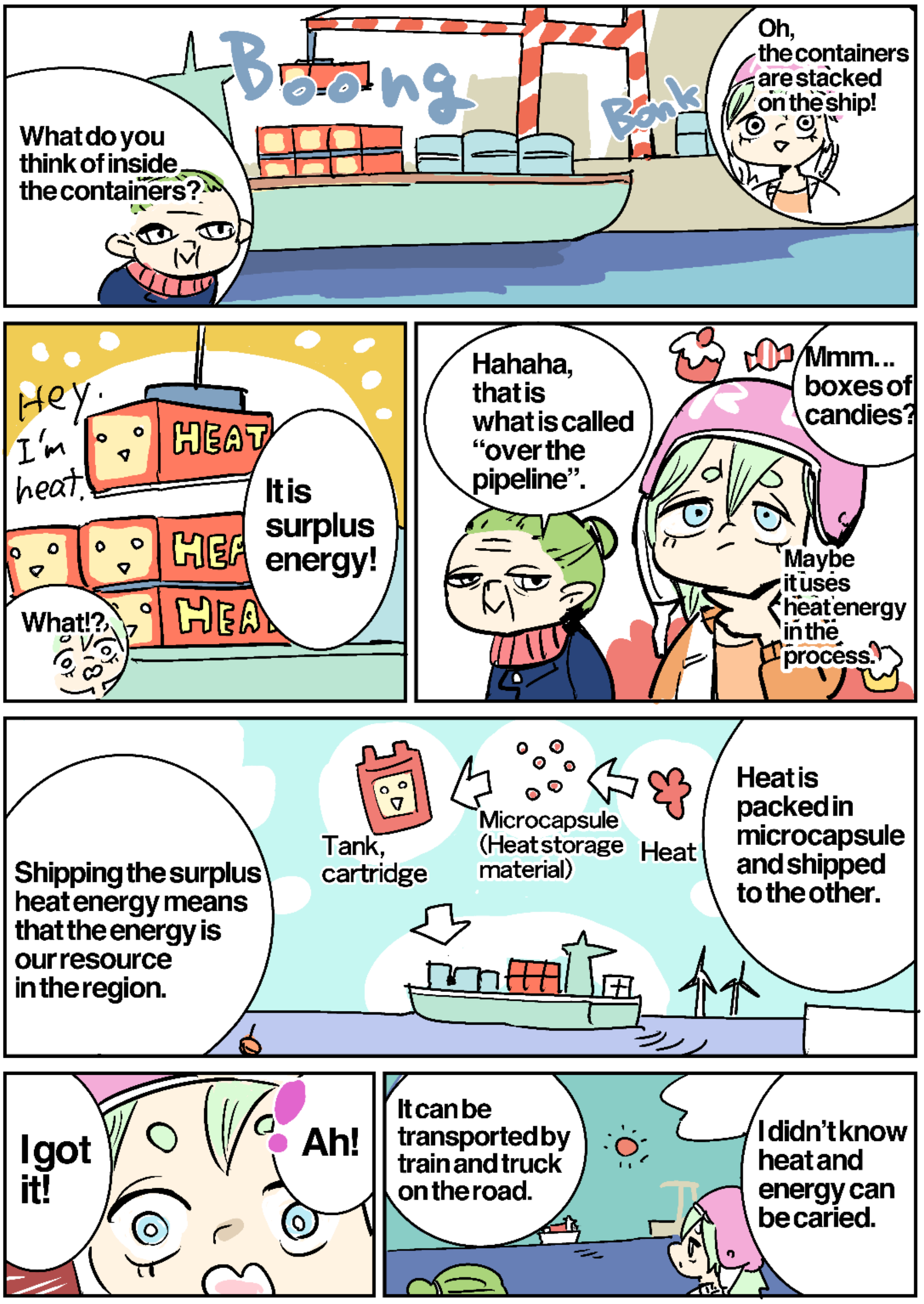

Eneko, Look at this.
Automatic management vinyl greenhouse
And you should take notice of this pipe.
ココ
Oh, It's your heat hub.
Yes.
Heat energy is stored in this hub for the house.
I'm large hub.
Yes. It is because the pipe is connected to large hub which is sharing in community.
I'm household.
What??
What??
This pipe... is going to opposite direction from grandma's house.


When energy is not sufficiently generated, take other's energy and if surplus, pass it to others.
Bring up.
No?
I thought energy was only used in the house.
Basically, it is.
Even each house create energy, it is common property in the town.
So saving energy increase the amount of energy to be used.
The large hub connected to house is connected to the larger hub.
That is constructing heat network over whole local towns.
フリーエネルギー ばんざーい
Cheers for free energy!!
I don't understand why we don't use surplus energy?
.....Well, seeing is believing.
Mmm. ...
In that process energy become surplus,
Which is the point.
We are full!!

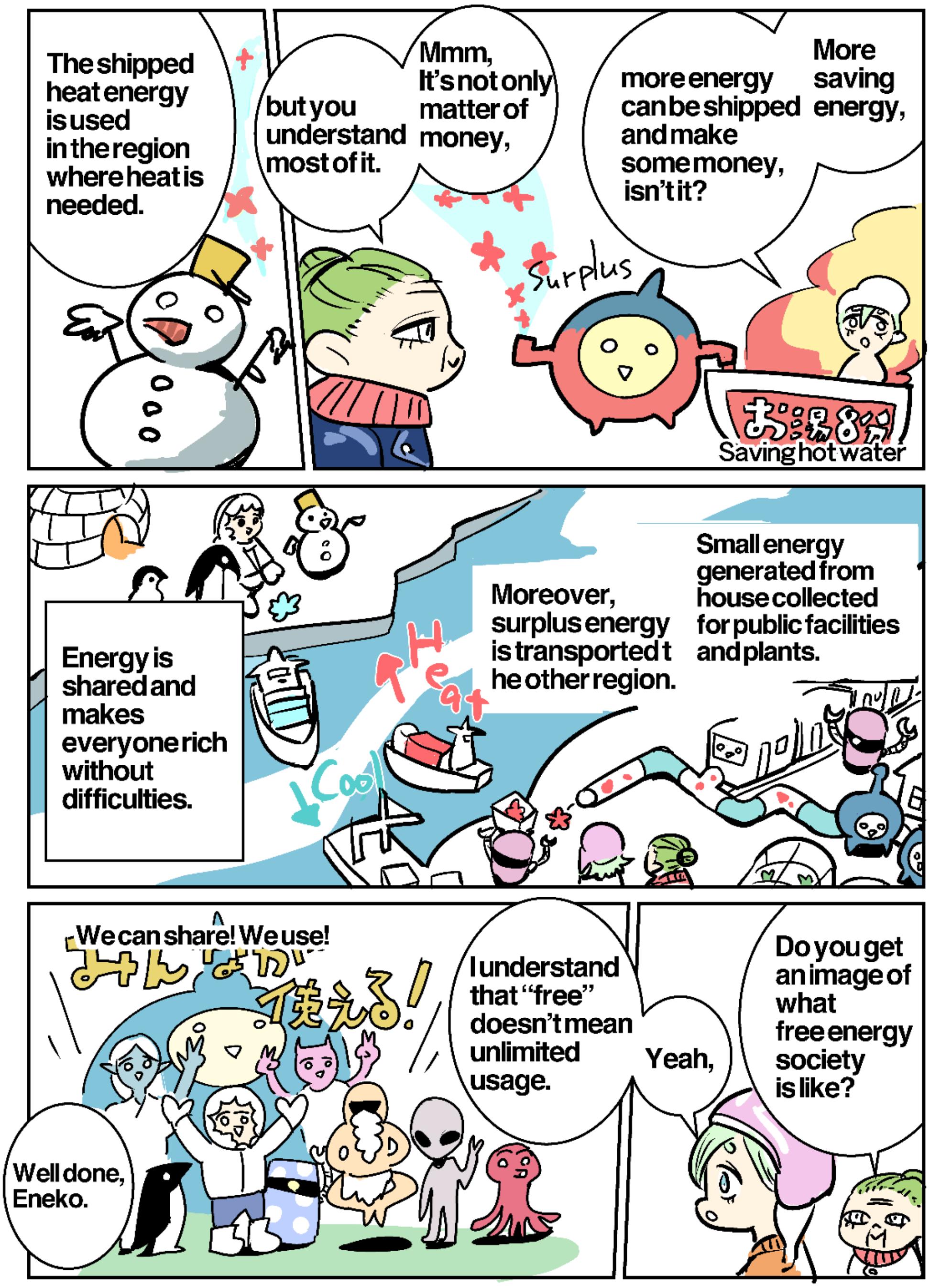

Clatter
Flick
Crack
Zi...i...iip
An electric motor scooter (30km/h)
autonomous driving control is implemented, charge at home.
Grandma! You are so cool!!
Swish
Haha hahaha ...
It is "over the pipeline".
ZAP
You will see the quintessence of free energy.
Swish
Wow!!


Hey, look! That is a train I took!
Local energy is used for infrastructure and public facilities.
Infrastructure is stabilized and that of fee is cheap, which makes our life in the rural area.
山川
There are many of greenhouses!
The fields along the pipeline effectively use heat inside of greenhouse and circle it.
Robots are in charge of jobs that people used to do. There is no hard working.
This is industrial area.
Plants used to smoke.
Now that image is disappeared.
Heat storage tank for winter

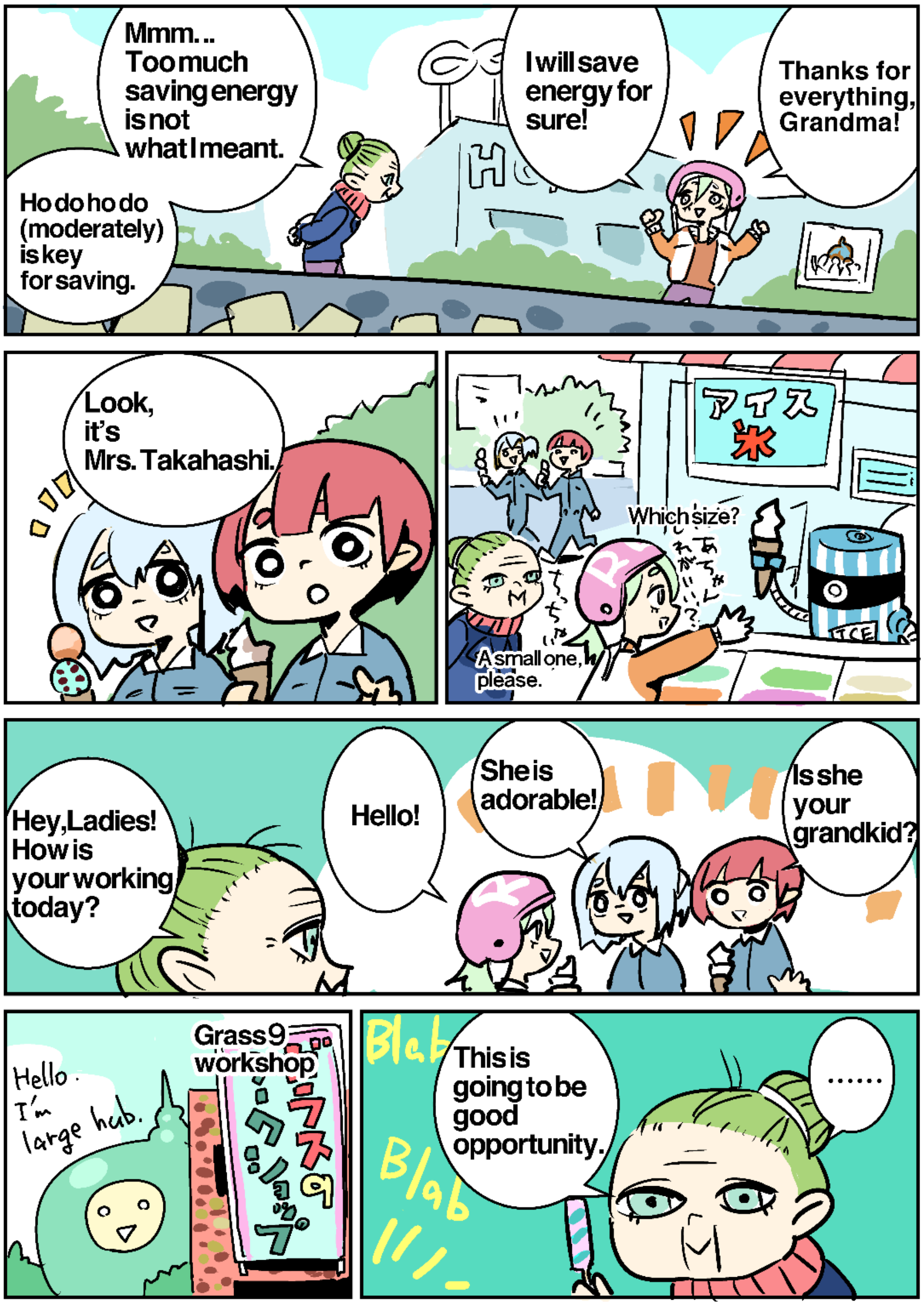

Offshore wind power
It's sea!
Wow!
We came to see where surplus heat energy was going.
It's beautiful but why we came to here?
No. look at that ship.
Robot collecting garbage.
Here is last destination.
What? Is the energy throwing away?

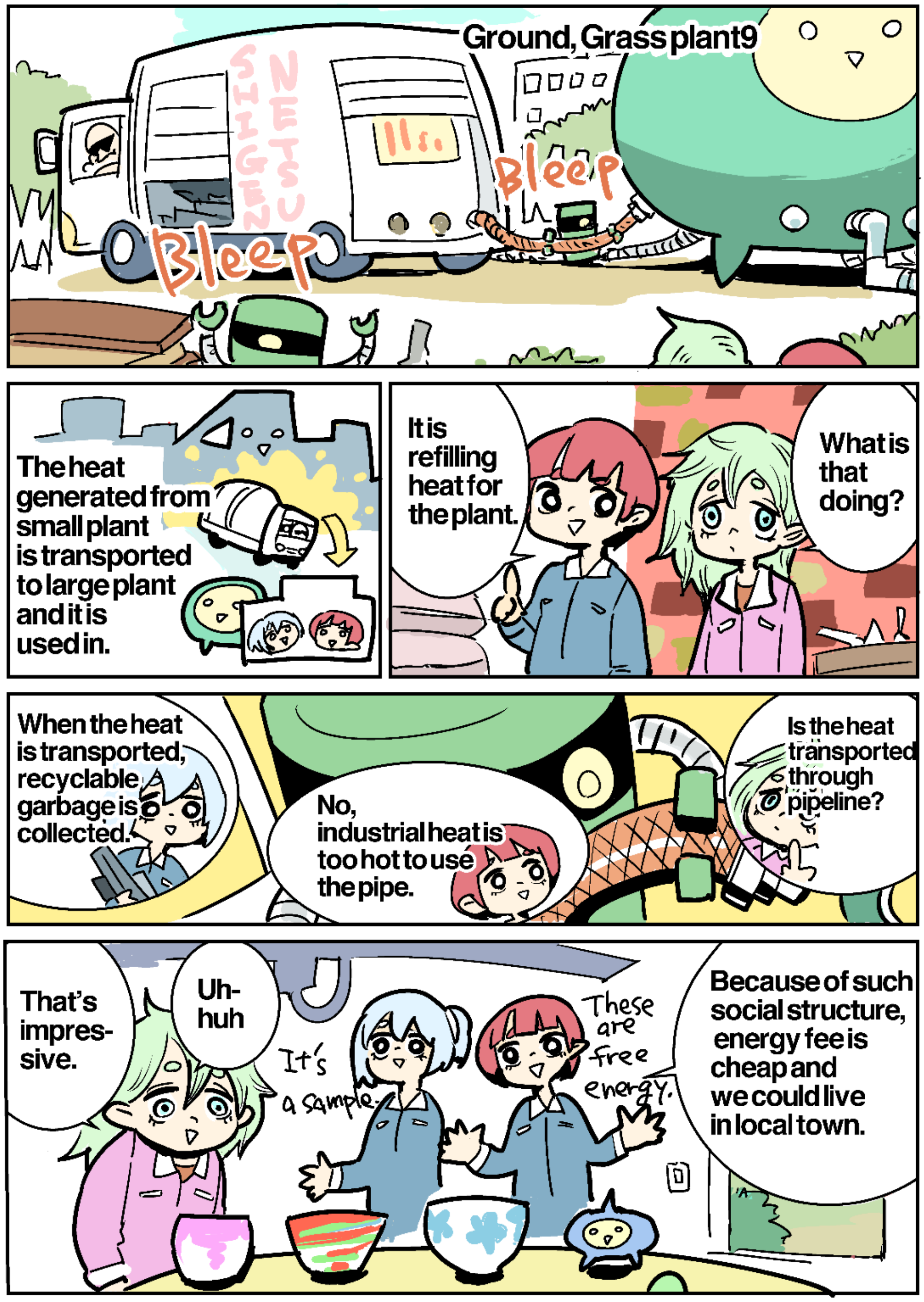


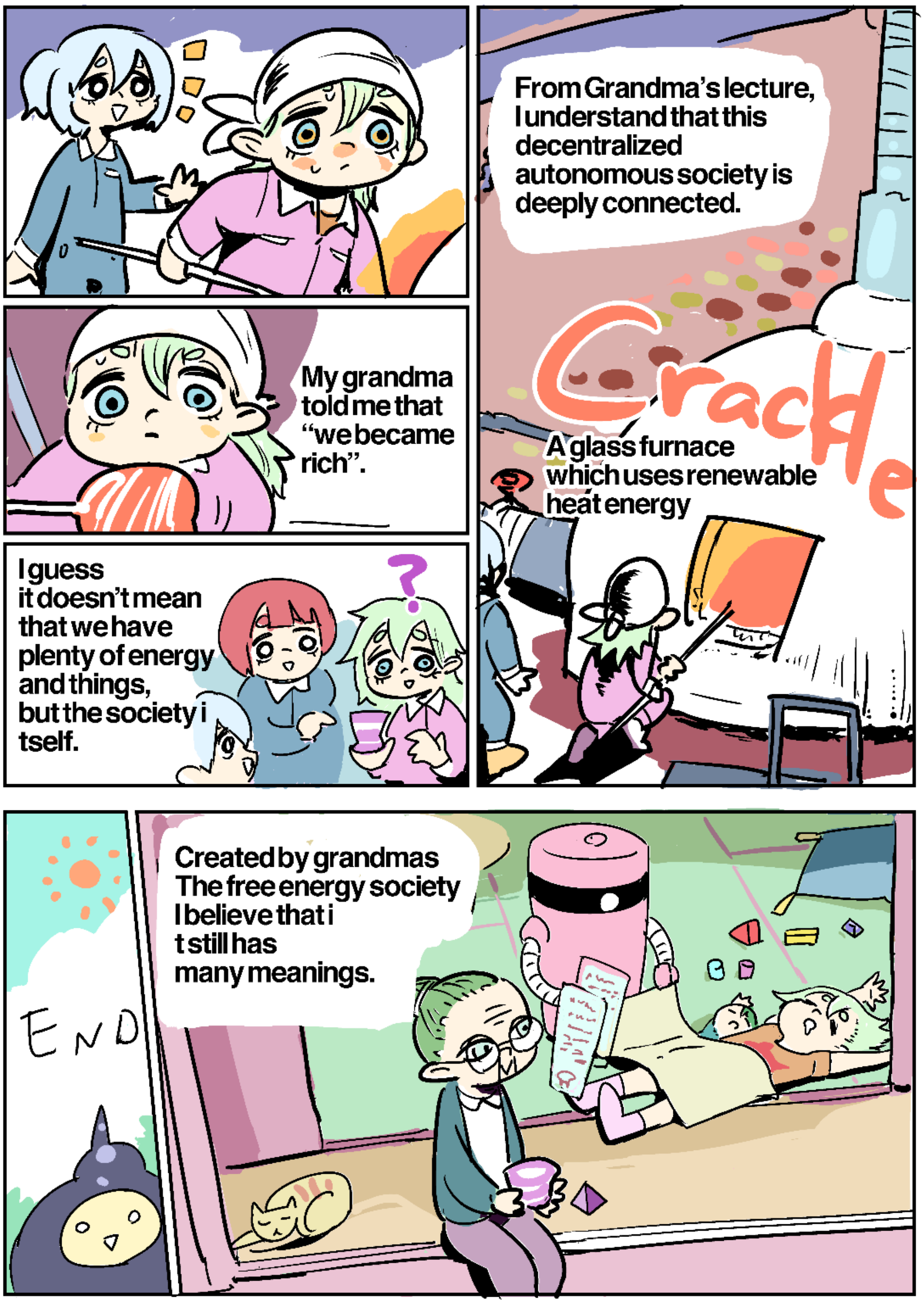
Boong
Bonk
What do you think of inside the containers?
Oh, the containers are stacked on the ship!
Hey. I'm heat.
HEAT
It is surplus energy!
What!?
Hahaha, that is what is called "over the pipeline".
Mmm... boxes of candies?
Maybe it uses heat energy in the process.
Shipping the surplus heat energy means that the energy is our resource in the region.
Tank, cartridge
Microcapsule (Heat storage material)
Heat
Heat is packed in microcapsule and shipped to the other.
I got it!
Ah!
It can be transported by train and truck on the road.
I didn't know heat and energy can be caried.



The shipped heat energy is used in the region where heat is needed.
but you understand most of it.
Mmm, It's not only matter of money,
more energy can be shipped and make some money, isn't it?
More saving energy,
Surplus
お湯8分
Saving hot water
Energy is shared and makes everyone rich without difficulties.
Moreover, surplus energy is transported t he other region.
Small energy generated from house collected for public facilities and plants.
Heat
Cool
We can share! We use!
みんなが使える!
Well done, Eneko.
I understand that "free" doesn't mean unlimited usage.
Yeah,
Do you get an image of what free energy society is like?


Mmm...
Too much saving energy is not what I meant.
Hodohodo (moderately) is key for saving.
I will save energy for sure!
Thanks for everything, Grandma!
Look, it's Mrs. Takahashi.
アイス
氷
Which size?
A small one, please.
Hey, Ladies! How is your working today?
Hello!
She is adorable!
Is she your grandkid?
Hello.
I'm large hub.
Grass9 workshop
ガラス9ワークショップ
Blab
Blab
This is going to be good opportunity.
......


Ground, Grass plant9
SHIGEN
NETSU
Bleep
Bleep
The heat generated from small plant is transported to large plant and it is used in.
It is refilling heat for the plant.
What is that doing?
When the heat is transported, recyclable garbage is collected.
No, industrial heat is too hot to use the pipe.
Is the heat transported through pipeline?
That's impres-sive.
Uh-huh
It's a sample.
These are free energy.
Because of such social structure, energy fee is cheap and we could live in local town.


My grandma told me that "we became rich".
I guess it doesn't mean that we have plenty of energy and things, but the society i tself.
From Grandma's lecture, I understand that this decentralized autonomous society is deeply connected.
Crackle
A glass furnace which uses renewable heat energy
END
Created by grandmas The free energy society I believe that i t still has many meanings.

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