SMART HEAT AND POWER (SHP) AGAINST DISASTER BY SOLAR AND BIOMASS COMBINATION UTILIZING THERMOELECTRIC CONVERTER

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1. Introduction

In Japan, the serious damages were occurred by the earthquake and seismic sea wave (Tsunami) called the Great East Japan Earthquake that was happened on March 11, 2011, and the electric power and heat source were immediately needed everywhere in the devastation area. It is especially expected to construct new philosophy of energy supply system which contains both thermal source and electric power generation. In addition, the system is fundamentally needed to decrease Green-House Gas (GHG) according to the universal consensus to realize the sustainable low carbon society.

The surrounded situation of energy in Japan has completely changed after the Earthquake. There are three problems. The first is energy supply after the Earthquake especially from the viewpoint of stable electric power supplies, the second is world pledge of 25% reduction of GHG compared with 1990 year until 2020, and the third is the introduction of renewable energies. To straighten out the energy problem while maintaining social revitalization, the nuclear reactor must be stably operated, and the world pledge of the GHG reduction must be kept, and there is no other method except increasing the ratio of renewable energy and also saving energy.

The power density of renewable energy like the solar energy, the wind force and any other sources is low, and even if tens of years pass from development, it is invariable that total cost is expensive as a fatal defect in the realization of renewable energy often called natural energy although the increase in efficiency and reduction in costs are advanced.

In the first, the possibility of renewable energy against a disaster is highly demanded that the system is independent and dispersed as an energy source, even when power failure occurs in the power grid. Secondly, a high total thermal efficiency is indispensable to enable the system cooperation in normal circumstances except for a disaster. Highly effective use and smart cogeneration, Smart Heat and Power (SHP), of solar energy are described below as an example.

The energy network named Smart Grid has already proposed by many researchers, governmental institutes and energy companies, moreover, we proposed additional concept of SHP to join the thermal and electric power storages, by all means, the concept is moved ahead the already presented Combined Heat and Power (CHP) that is popular in Northern Europe utilizing wood biomass from the forest and developed the ideas of SHP by us. There are three important points to take full advantage of the solar energy. Firstly, the solar system itself has to make effort to maximize total thermal efficiency. Secondly, another energy supply is needed to combine the solar energy, for example, with the biomass such as wood biomass stove for firewood or woody pellet utilizing thermoelectric converter (TEC). Thirdly, the combined system has to maximize total thermal efficiency, moreover, the system is needed to maintain the best performance in storage systems charging and discharging both heat and electric power, by keeping independent or harmonizing with the power grid.

2. High efficiency utilization of solar energy

The intensity of solar energy is 1.37 kW/m^2 in the space of outer atmosphere of the earth, and the direct sunshine on ground of the earth is about 1.0 kW/m^2 in perpendicular to the sunshine rays. The energy spectrum of sunshine on the earth has many absorption bands caused by ozone, water, oxygen, and the carbon dioxide, and other gases in the atmosphere. By realizing the energy utilization as high thermal efficiency, it will be possible to perform the reduction of fossil fuel consumption, GHG generation and the expensive cost, respectively. Therefore, many efforts has been performed to develop high thermal efficiency, the effort has been also conducted in the utilization of solar energy.

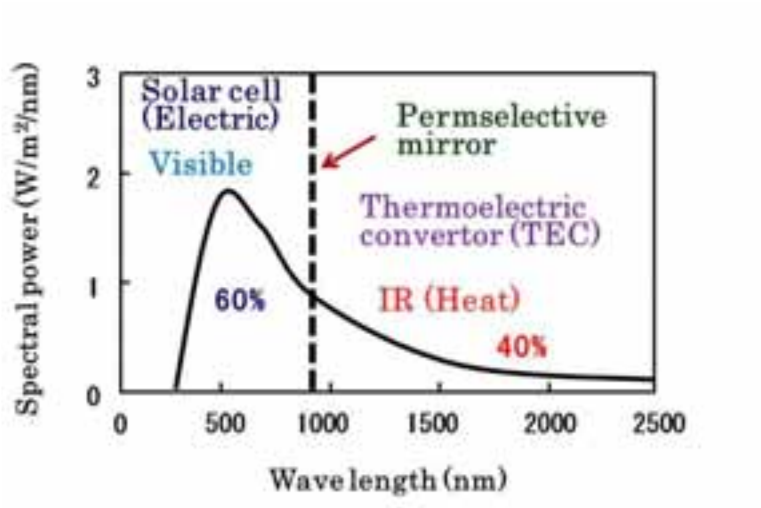

Fig. 1: Solar energy utilization by permselective mirror

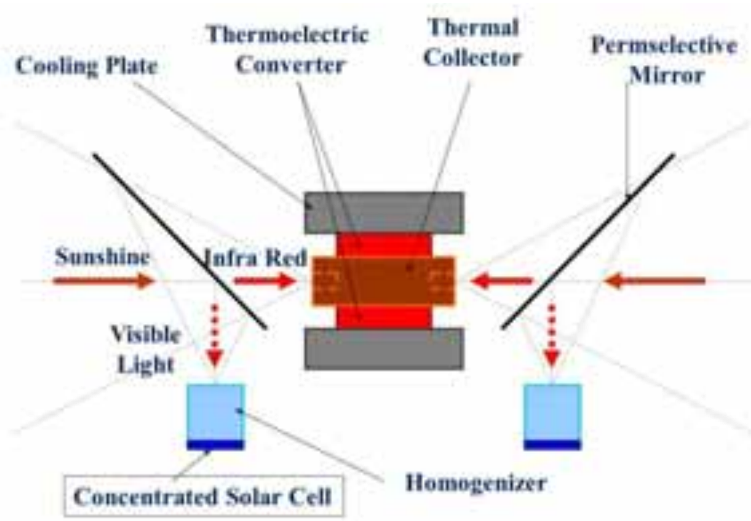

Fig. 2: Full spectrum utilization method of both visual and infra red of solar light

Kisara and Niino et al. (2008) of the Japan Aerospace Exploration Agency (JAXA) have been attempting to utilize whole spectrum of solar ray. Figure 1 shows the relation between spectrum power and wave length of solar light at outer space of the earth which have no absorption by the surrounding atmosphere, and also shows the separation method by permselective mirror. The region of shorter wave length is mainly visible light and the longer wave is infrared ray, respectively. Figure 2 shows the apparatus of power generation and thermal utilization to divide solar light into two regions of visible and infrared rays by permselective mirror. The electric powers are generated by visible light with solar cell and infrared light by thermoelectric converter (TEC). The thermal energies are also able to be collected by heat removal from cooling technology for concentrated photovoltaic solar cell and for thermoelectric converter. The separated energy is about 60% by visual light and 40% by infrared, respectively. The dividing method of solar light by permselective mirror is able to realize whole energy use and it is possible to use all energy without uselessness.

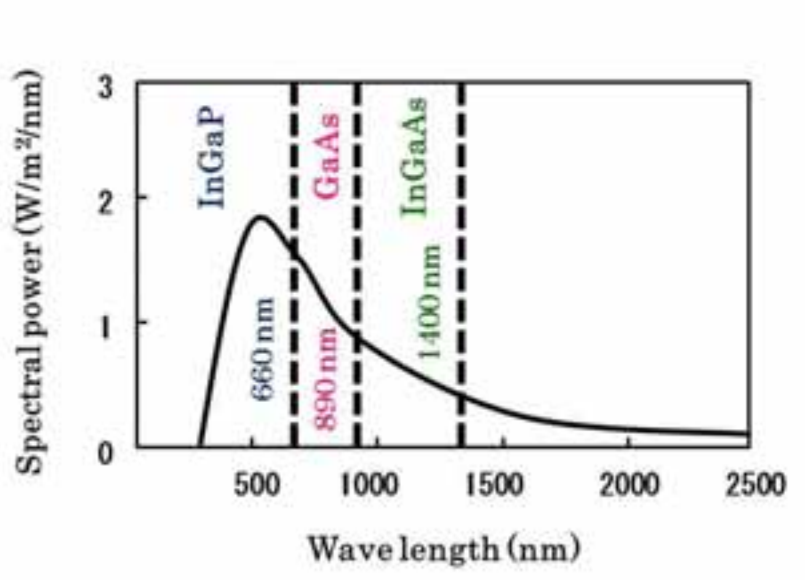

Fig. 3: Three layer separation of solar light by compound photovoltaic cell, ref. Sharp corporation

Figure 3 describes the diagram of spectral power and wave length for multi-junction solar cell based on the technical report by Takagi (2010) in Sharp Technical Journal. This type of solar cell is constructed by three layers of photovoltaic semi-conductor, visible shorter wave than red, two zones of infrared ray, in which the thermoelectric converter is not used.

There are many methods to realize high total thermal efficiency in solar energy utilization, and many combinations are considered among photovoltaic solar cell, thermoelectric converter (TEC), and dividing wave length zone, for example, visible light and infrared ray, in the followings.

(a) Only visible light solar cell power generation
(b) Visible light solar cell power generation, infrared ray thermoelectric power generation, and waste heat recovery
(c) Visible light and infrared ray solar cell power generations, and waste heat recovery
(d) Visible light and infrared ray, only thermoelectric power generation
(e) Visible light and infrared ray, thermoelectric power generation and waste heat recovery

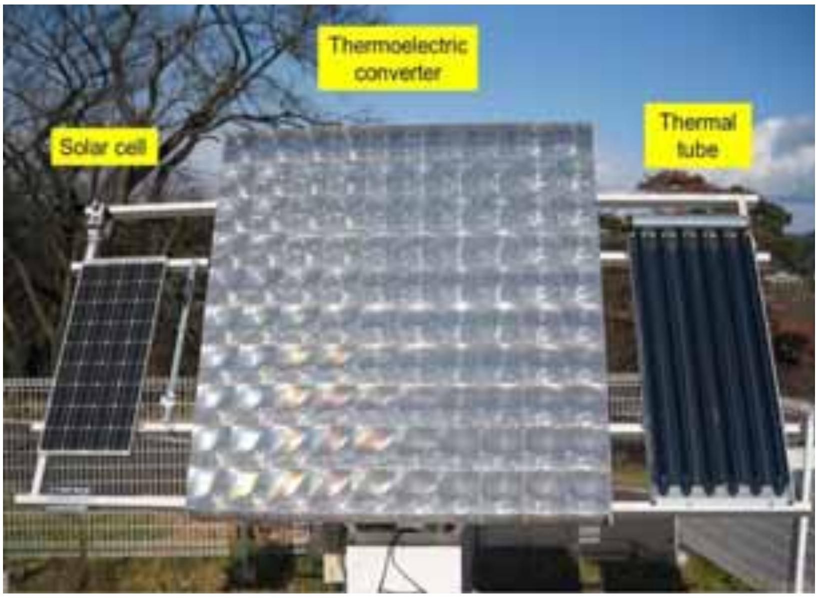

Fig. 4: Solar tracking system in Miyagi University

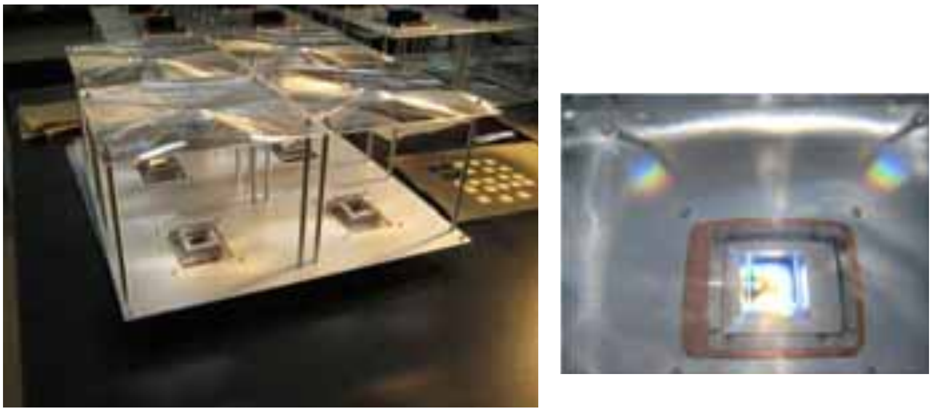

Fig. 5: Concentrate unit by Fresnel lens and thermoelectric conver

Figure 4 shows the thermoelectric power system by solar tracking device installed at Miyagi University in Japan. Thermoelectric converter (TEC) device is installed on the center, the left and right sides are Photovoltaic (PV) solar cell and solar thermal tube device, respectively. The solar tracking TEC device is 2 m square in dimension and that is composed of 100 units of 200 mm square TEC single unit, however, which has no permselective mirror. The TEC device is the system (d) visible light and infrared ray, only thermoelectric power generation, described above in the five classifications. Figure 5 also shows the smallest TEC single unit which has 200 mm square clear panel of acrylic plastics Fresnel lens. The composite of TEC is 20 mm square in dimension of bismuth telluride and cooling device is thermal fins. The concentration ratio of solar light is about 100. The experimental result by the solar system indicates some technical problems such as thermal contact resistance to improve the efficiency of TEC, moreover, it is clarified what is the most valuable technology to get high total thermal efficiency by utilizing both heat and electric power.

3. Biomass utilization

Figure 6 shows the performance of experimental study in which the power generation by thermoelectric converter is proved under the condition of wood pellet combustion. Biomass stove is often used in cool and cold seasons as the heater to maintain the temperature comfortable inside the house for a long time. Biomass stove is always able to charge the electric power when the room heating or cooking is done in the house, it will compensate the defects that the solar energy cannot be generated in nighttime and the period of cloudy, rainy and snow weathers. Yano, T., and Hoyama, K., et al. (2010) showed the experimental result of possibility to charge the batteries and mobile phone, and also showed the possibility of combined system both heat and electric power utilizing wood biomass, thermoelectric converter and solar energy.

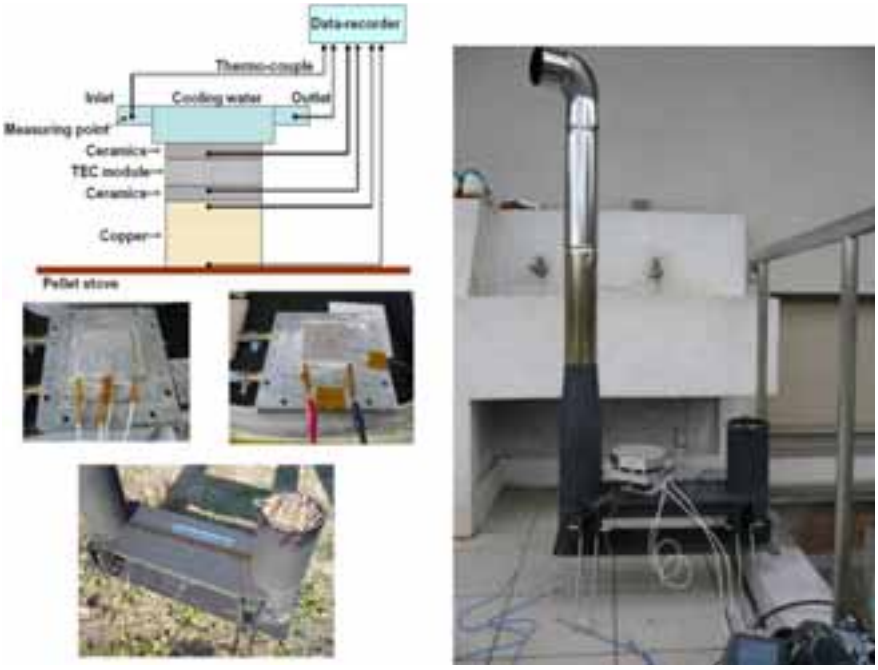

Fig. 6: Power generation by thermoelectric converter with biomass pellet stove

4. Smart Heat and Power (SHP)

The solar power generation has two major defects which are no continuity in daytime and low power density. The solar system is not able to generate heat and electricity at nighttime, and the solar power is very small in rainy and cloudy days. Moreover, the power ratio in average of unit year that can be actually used in Sendai city of Japan is only 12 % as shown by Suginome, S., Yano, T., et al. (2010), compared to the total efficiency concerning the equipment ability. Then, the combination of solar power and biomass, and other renewable energy is expected to make power equalization and also full use of heat and electric power storages.

Figure 7 describes the concept of the Smart Heat and Power (SHP) by utilizing renewable energy. The main advantage is the heat and power storages. The renewable energy, such as solar photovoltaic cell, solar thermal, wind power, geothermal, small hydro power, biomass co-generation etc., will be combined to make full use of the characteristics of renewable energies, and also it is possible to connect with the power grid in most effective patterns.

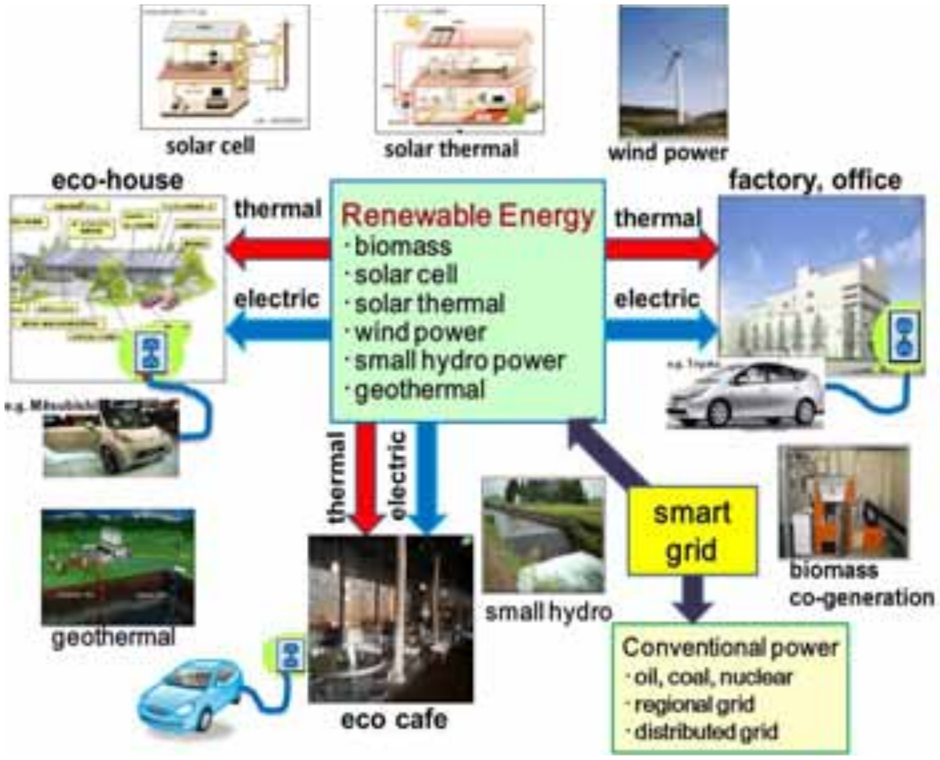

Fig. 7: Smart Heat and Power (SHP) by renewable energy

5. SHP against a disaster

What system is desired in the disaster by the earthquake and seismic sea wave such as the Great East Japan Earthquake? The answer is four items that are, in very short terms, the electric power, heating, water and food. To add more supplementary statement, it is needed that the electric power, heating and hot water, drink water and daily life water, and of course, food system to maintain their lives.

Figure 8 describes Smart Heat and Power (SHP) against a disaster. In this figure, the wood biomass such as wood wastes and forest thinnings are used, and solar thermal tube and photovoltaic cell are combined in the disaster system. When the disaster happens, there was a portable power generator by gasoline or portable gas burner, however, there was no gasoline or portable gas canister, if there were not only small amount of fuel in a coming short time, the fuel supply cannot keep up with the rapid increase of fuel demand. It is needed to introduce the SHP into the preparation system against a disaster. The main concept of SHP against the great disaster such as big earthquake is the fully independent and perfectly dispersed power system. Moreover, the introduction of renewable energy into SHP against a disaster is remarkably effective for the lack of fossil fuel such as oil or coal. The thermoelectric convertor (TEC) has not a mechanical or movable part, which can expect high reliability, and can also combine the biomass combustion equipment, sunlight, and heat. Moreover, reliability rises rapidly if electricity is charged to the rechargeable battery by this combination and heat is stored in thermal storage equipment.

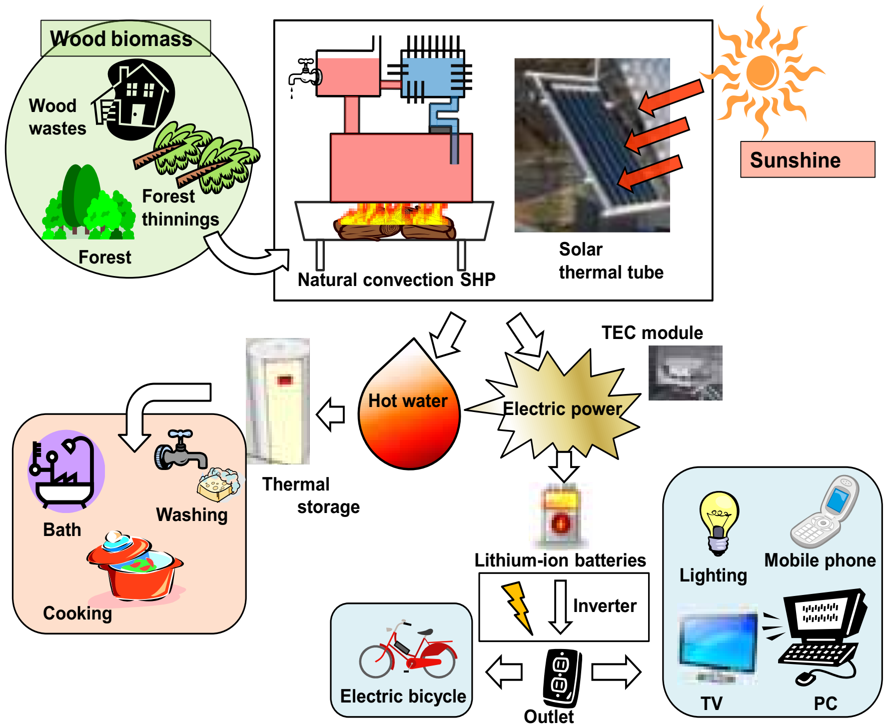

Fig. 8: Smart Heat and Power (SHP) against disaster

6. Total thermal efficiency

The most important issue is the total thermal efficiency in utilization of renewable energy, which determines the cost reduction of energy system and decrease of green-house gas (GHG). In many case, especially in solar energy, the most heat is exhausted from solar cell after electric power generation. When the high thermal efficiency is realized, the cost and GHG emission dramatically decreases. Figure 9 shows the comparison of total thermal efficiency. (*a*) The maximum efficiency of photovoltaic power generation is about 20 % in the market, according to the result of a recent research and development, the power generation efficiency has been rised up to about 42 % in a champion data, (*b*) Visible light solar photovoltaic power generation, infrared ray thermoelectric power generation, and waste heat recovery, the sunlight separation and heat recovery shows about 55 %, (*c*) solar thermoelectric power generation with visible and infrared rays, and the waste heat recovery is ideally expected to 80 % , (*d*) combination of biomass combustion in the room, TEC power generation and waste heat recovery also expected to 80 %, when the heat recovery is consumed at the nearest site, such as fuel cell system has already shown within the house. The dotted line of (*c*) and (*d*) in Fig.9 show several per cents of electric power generation in general efficiency by TEC, however, the recent research and development describe that the efficiency of power generation by TEC will become 15 % in near future.

Figure 10 shows the concept model of plant factory by greater use of renewable energy and Smart Heat and Power (SHP). This concept describes the example of SHP utilization in usual day, however, which will be utilized as the independent and dispersed power system for a disaster even in the blackout of conventional power grid.

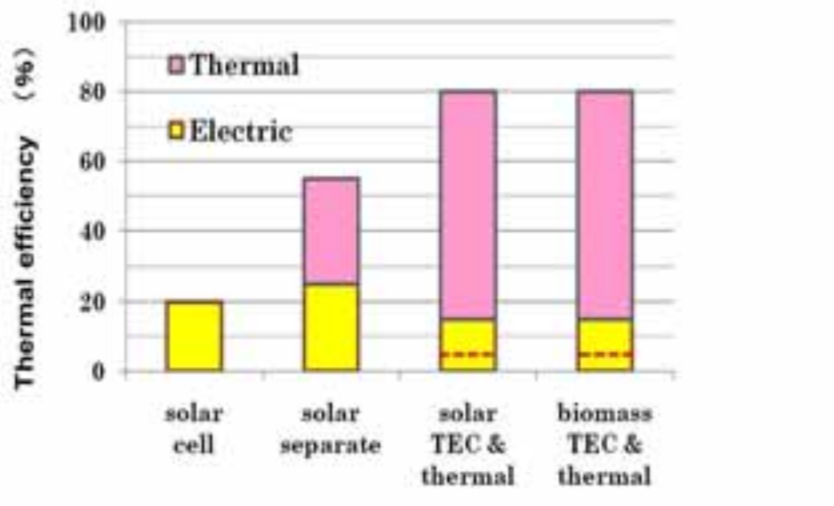

Fig. 9: Total thermal efficiency combined solar and biomass utilization

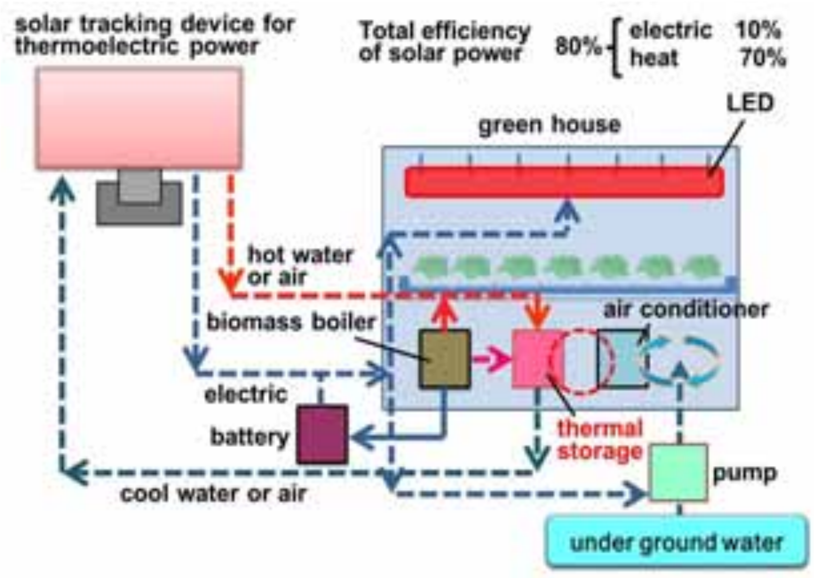

Fig. 10: Plant factory model by renewable energy and Smart Heat and Power (SHP)

7. Conclusion

To utilize the renewable energy more efficiently, it is needed the storage technologies of thermal power as heat and electric power, by combining of different renewable energies such as solar and biomass. The concept of Smart Heat and Power (SHP) system is described here and SHP has two types of storages for electric power and thermal power. To perform high thermal efficiency, the distance between electric power generation and heat source is needed as short as possible, moreover, the shortest distance from heat consumption position is desired.

Moreover, to realize SHP against a disaster, the system has to be independent and distributed perfectly. The key point for a disaster is to supply the electric power, heating, water and food at an instant. When the SHP against a disaster has the water and food supply systems, it will become full service system in a disaster such as the great earthquake.

8. References

Kisara, K., 2008. Sunlight heat combined cycle power generation system, Thermoelectric conversion technology handbook, NTS corporation, Tokyo, 533-539.

Yano, T., Ikedo, S., Hoyama, K., Orikasa, T., Kisara, K., Niino, M., Tohji, K., 2009. Biomass Utilization System for Dispersed Power Source by Lithium-Ion Secondary Battery and Charging System for Automobile, Proceedings of the 17th European Biomass Conference, Hamburg, Germany, 29 June–3 July, 582-586.

Takagi, T., 2010. Sharp Technical Journal, Compound solar cell, 100, 28-31, in Japanese.

Yano, T., Hoyama, K., Suginome, S., Ishii, Y., Orikasa, T., Niino, M., Suzuki, K., Kisara, K., and Ishikawa, T., 2010. Combined system both heat and electric power utilizing wood biomass, thermoelectric converter and solar energy, Proceedings of the International Conference on Renewable Energy 2010, 27June-2July, Yokohama, Japan, O-He-1-6.

Suginome, S., Yano, T., Ishii, Y., Hoyama, K., Niino, M., Suzuki, K., Kisara, K., Ishikawa, T., 2010. Evaluation and prediction of solar energy utilization for plant factory and Eco-Cafe, Proceedings of the International Conference on Renewable Energy 2010, 27June-2July, Yokohama, Japan, P-Pv-97.

Yano, T., Kisara, K., Suzuki, K., Ishikawa, T., Niino, M., 2011. Coexistence both thermoelectric converter and photovoltaic cell, Materia Japan, The Japan Institute of Metals, 50, No.4, 158-160, in Japanese.

Toshikazu Yano, et al., 2010. Possibility of maximum thermal efficiency in solar tracking system utilizing thermoelectric converter, 11th International Symposium on Multiscale, Multifunctional and Functionally Graded Materials, Guimarães, Portugal, 26-29 September.

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