Contributing to Society Through Collaborative and Integrated Research and Development

Aiming to Innovate Energy Technologies

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Fuji Electric Co., Ltd., which "contributes to the creation of responsible and sustainable societies through our innovation in energy technology," and the National Institute of Advanced Industrial Science and Technology (AIST), which promotes green innovation by "bringing technology to society," have a long-standing collaborative relationship that includes the research and development of SiC. Fuji Electric Executive Officer Dr. Eguchi Naoya invited AIST Vice-President Dr. Yabe Akira to exchange opinions about the future of research and about ways of contributing to society.

SiC device development and other collaboration in the Energy Sector

Eguchi: AIST and Fuji Electric have a collaborative relationship in the energy sector, which includes SiC (silicon carbide) device development, and together have produced various successful results. Today, I will be speaking with Dr. Yabe, Vice-President and Director General of AIST, and have been looking forward to this opportunity tremendously. Welcome and thank you.

Under a policy of "through our innovation in electric and thermal energy technology, we contribute to the creation of responsible and sustainable societies," Fuji Electric is working to develop next generation technology. Having already made vast contributions to society with electrical energy technology and thermal energy technology, Fuji Electric intends to continue to focus on energy technology more and more in response to the energy and environmental problems of recent years.

Fuji Electric has cultivated core technologies and expanded its business in the three fields of electrical energy technology, thermal energy technology, and energy management technology for the optimal control of these types of energy.

Yabe: AIST was founded in 2001, facing the 21st century. The 15 research institutes of the former Agency of Industrial Science and Technology, Ministry of International Trade and Industry, which were separated by research fields into the Electrotechnical Laboratory, National Metrological Institute of Japan Mechanical Engineering Laboratory and so on, were combined together, and reorganized to one National Institute to focus on our mission. As a result, we are now able to focus not only on basic research, but also widely on applied research and actual proof research in cooperation with many companies. The failure to follow through and industrialize the results of R&D has been likened to a "nightmare" or a "death valley

of research and development" and the development of a methodology to overcome such difficulties is the mission given to AIST, and we are working towards that end.

Eguchi: Researches of AIST with an emphasis on practical applications are, from a corporate point of view, extremely welcome. Although the catchphrases of "industry-academia collaboration," "industry-government-academia collaboration," and "open innovation" have been in existence for some time, these had been advanced in form rather than substance. AIST addressed this directly. We are certain that such an initiative would be effective in invigorating Japanese industry. To take advantage of open innovation, we have sent people to AIST, where they engaged in joint R&D. I feel that they are really moving toward practical application, and the things Dr. Yabe spoke about are truly being carried out.

At AIST, Dr. Yabe, you oversee the environment and energy field, don't you?

Yabe: Research at AIST is separated into the six fields of: environment and energy; life science and biotechnology; nanotechnology, materials and manufacturing; information technology and electronics; geological survey and applied geoscience; and metrology and measurement science. The environment and energy field, which I oversee, is charged with an extremely important mission that encompasses energy problems, environmental problems and the like, and for that reason has many researchers, and the combined number of postdoctoral fellows and researchers sent from companies is nearly 1,700 people, which is approximately one quarter of the total number of researchers at AIST.

The environment and energy field is working on three major themes. One theme is the promotion of energy technology through the efficient use of renewable energy, energy savings and the like. The second theme is the promotion of the recycling of materials and the circulation of materials. And the third theme is the development of methods of evaluating energy and environmental technology.

New form of open innovation: Tsukuba Power-Electronics Constellation (TPEC)

Eguchi: We again recognize that the field overseen by Dr. Yabe is also a core field for Fuji Electric.

Presently, Fuji Electric is most focused on SiC technology for next-generation devices. Our research and development activities in this field have been conducted jointly with AIST, beginning with the exploration phase.

Yabe: Present-day inverters have been made compact in size, but an overwhelmingly more compact size can be realized by incorporating devices that use new materials such as SiC. Inverters for railroad and automotive applications had, until now, occupied a significant amount of space, but by using SiC devices, the inverter size and weight can be reduced to a fraction of their present values, and constraints on installation can be reduced dramatically. The widespread adoption of inverters is expected to result in energy savings that, roughly estimated, would be equivalent to approximately 6% of Japan's total energy consumption. For the purpose of mitigating Japan's energy problems, the practical application of SiC inverters would seem to be an extremely important technology.

In April 2010, AIST established the Advanced Power Electronics Research Center to conduct full-fledge research on practical applications of high-performance power conversion technologies that make use of wide-bandgap semiconductor materials such as SiC.

Also, AIST has continued to promote the "Industrial Transformation Research Initiative" as a new structure for industry-government-academia collaboration. Fuji Electric and ULVAC, Inc. have participated as a part of that initiative and from FY2009 through FY2011, "a study of SiC trial production and a system application demonstration" were carried out by the three parties jointly. Sample devices that incorporate basic SiC technology established thus far were manufactured and their high-performance and compact size appealed to various system manufacturers, and this, I think, is a major achievement.

Eguchi: The participants from Fuji Electric, in addition to R&D personnel, also include members who work on a production line on the factory floor every day. This approach was completely different from the past and was also very challenging for management. However, the results from FY2009 through FY2011 will certainly lead to practical applications, and this is extremely important, I believe, for Fuji Electric and for the future of Japanese industry.

Yabe: Our experience has also been very valuable. A new organization that takes this approach one step further is Tsukuba Power-Electronics Constellations (TEPC), which was founded in April 2012. TEPC has four main members of Fuji Electric, ULVAC, Inc., AIST and Sumitomo Electric Industries, Ltd., and operates with about 30 institutions in total. While watching from entrance to exit, collaborating from upstream to downstream, and at times working towards various goals as rivals, we approach practical application. In this way, we are summoning our full strength to advance energy savings to the extent

EGUCHI Naoya

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possible throughout the world.

Eguchi: Until now, it had been difficult to gather together rival companies to accomplish a single task. However, in consideration of the situation in Japan now, the participants are aware of the importance of being a global leader in technology such as SiC, and the cooperation among companies is a tacit acknowledgement of such. I believe that the skills obtained here can certainly be shared among members and utilized in each company's business. We must lead the world with SiC technology. That is my desire.

Yabe: In terms of technology, we are now attempting to overcome the "death valley." At such a time, unless all parties quickly come together and cooperate to build one thing, we will be surpassed by the global competition. It is extremely important for there to be accelerated by open innovation.

Eguchi: SiC exhibits not only low loss and high breakdown voltage characteristics, but also has a high degree of potential capability for various applications such as for use in vehicle engines, and it would be too much for a single company to master all of these thoroughly. TPEC members include various companies whose expertise ranges from materials to applications, and from this collective wisdom, we expect that different ideas will emerge and be realized.

Fuji Electric is considering the use of SiC in all of its existing power electronic components. It is well known that SiC can be used to make devices that are lighter and smaller than devices made of silicon. We also found that SiC seems to be usable in devices having specifications ranked one-level below those of silicon devices, and in consideration of this, we estimate that the initial and running costs will be cheaper. As of October 2012, we began to build various components, such as uninterruptible power supplies (UPSs), power conditioners (PCSs), inverters, matrix converters and switching power supplies for servers all at once.

Yabe: That is a very encouraging story. SiC devices are rather difficult to develop and require complex technologies. It is not something that can be imitated with makeshift technology. Once achieved, such technology is expected to lead the world for a long time.

Eguchi: In our collaborative research with AIST thus far, we have been able to obtain data about how exacting the processes will be when building a mass-production line and the rate of return that can be expected for a given size of investment. The ability to perform analyses prior to full-scale mass-production is a groundbreaking approach from the perspective of realizing practical applications, and had not been possible in prior industry-government collaboration. On the basis of such data, Fuji Electric makes estimates and accelerates the construction of SiC-related mass-production facilities.

Yabe: I believe that analyzing the data necessary for practical application is an essential requirement in order to cross over the "death valley" and to lead the world.

Efficiently utilizing thermal energy with heat pumps

Eguchi: We have been talking about electrical energy so far, but under Fuji Electric's management policy of "through our innovation in energy technology, we contribute to the creation of responsible and sustainable societies," we are also paying attention to thermal energy, and are thinking about technology that can use thermal energy effectively.

Thermal energy, qualitatively speaking, is energy in its final stage, and a large portion of such is often discarded. According to a certain estimate, Japan uses approximately 20,000 Peta*1 joules of primary energy per year, and this is equivalent to about 480

*1: Peta : 10^{15}

million tons of oil. Of this amount, however, 45% will eventually be discarded as heat and this is a huge waste of energy.

Yabe: Thermal energy is my field of expertise.

Thermal energy is used in a significantly large quantity, and accounts for about half of the overall energy consumption at AIST for cooling, heating, cleanroom air conditioning and the like. In the last 5 years at AIST, we have realized a 15% reduction in total energy consumption. The majority of this reduction is a result of the effective use of thermal energy. AIST formerly made annual payments of about 4 billion yen for energy, and a 15% reduction corresponds to a savings of 600 million yen. Considering that 600 million yen can now be diverted to research expenses, I think that the efficient use of thermal energy is an important matter.

The effective use of thermal energy has been supported by the progress of heat pumps. Heat pump performance is measured by a coefficient of performance (COP) value that indicates, for a given consumption of electrical energy, the multiple of thermal energy that will be obtained, and the heat pumps available on the market today have COP values of around 6. Such a value means that, for example, if a 1 kW electric heater was previously required for heating, that same 1 kW of heat can now be obtained using a heat pump air conditioner of 170 W, that is one-sixth of the electric heater.

We have moved on from the era in which fossil fuels were used for heating and supplying hot water. In the present era, electrical energy, which is one form of energy, is intervening in major thermal energy applications, such as cooling and heating and supplying hot water. I believe this to be a huge innovation.

Thermal energy is an important energy for uses that include cooling and heating, but our ways of using thermal energy are still quite wasteful, and there is still room to reduce such usage.

Eguchi: You mentioned heat pumps, and in 2012, Fuji Electric, a manufacturer of vending machines, launched a model with advanced heat utilization. With a structure that utilizes heat from outside air as well as exhaust heat from a cooling chamber to adjust the temperature of a heating chamber, the energy consumption was reduced by 40% compared to the prior year's model. The energy consumption of vending machines has been reduced to one-fifth over the course of fifteen years, but the further reduction by 40% all at once in one year made us realize the tremendous effect of heat pumps.

Yabe: Heat pumps that produce thermal energy are a world-leading product from Japan, and their use in constructing systems such as vending machines is actually very important and is attractive energy-saving technology that should have appeal worldwide.

YABE Akira

Born in 1952. Completed PhD in Mechanical Science and Engineering, Graduate School of Science and Engineering, Tokyo Institute of Technology in 1979. Joined Mechanical Engineering Laboratory of Agency of Industrial Science and Technology, Ministry of International Trade and Industry. Head of Fluid Engineering Research Lab, Department of Energy in 1995. Head of Quantum Engineering Research Lab, Extreme Technology Department in 1997. Concurrently Head of Mechanical, Quantum and Molecular Engineering Special Research Laboratory in 1998. Head of Planning Office for Mechanical Engineering Lab in 1999. Served as Director for Advanced Manufacturing Research Center on Micro and Nano Scale Science and Engineering, National Institute of Advanced Industrial Science and Technology (AIST), Director of Chugoku Regional Research Center, Chief of Biomass Technology Research Lab, Chief of Research Collaboration Promotion Department in 2001. Served as the Vice-President of AIST since 2008. Concurrently Director General for Environment and Energy Research Fields. Presently, also serving as President of the Japan Society of Mechanical Engineers (JSME), as Member of Science Council of Japan, Chairman of Fine Bubble Industries Association (FBIA), Professor (Cooperative Chair) of Dept. of Mechano Micro Engineering, Tokyo Institute of Technology, Adjunctive Professor of Cooperative Graduate School of Kanazawa Institute of Technology, Director of Technology Research Associations of R&D Partnership for Future Power Electronics Technology (FUPET), FC-Cubic (Fuel Cell Cutting-Edge Research Center) and Photovoltaic Power Generation Technology Research Association (PVTEC).

Additionally, everyone is presently studying industrial-use high-temperature heat pump systems with the goal of future realization. The public still does not use waste heat very much, and often discards it. A waste heat system would pump this waste heat and raise its temperature up to 160 °C. At present, boilers are used in industrial applications, but because boilers require long pipes, they have the disadvantage of large thermal loss. Heat pumps can be individually installed at required locations, and are an effective technology for reducing global warming.

AIST would like to gather the collective wisdom throughout Japan and research and develop this technology.

Cultivating binary generation technology with geothermal technology

Eguchi: Now, AIST is hosting a technical symposium for unused thermal energy.

Yabe: Yes, that is correct. For about the past 30 years, AIST has been working on waste heat utilization and the use of heat pumps to boost tem-

peratures. In the case of renewable energies, there are maps that show where the wind is strong, but there are no maps that show unutilized heat, such as which factory is discarding what quantities of heat. If such a map did exist, we believe that there would be a greater possibility of using heat effectively within a factory or industrial complex, and are therefore intensifying our efforts.

Eguchi: From the viewpoint of using heat effectively, not only usage of heat as heat and conversion of heat to electricity in an intermediate process, but also binary generation using low temperature hot water and exhaust heat from a factory are conceivable.

If we also think about converting geothermal heat, having been discarded at low temperature, into electricity, then I think there is the potential to conserve even a little more energy with thermal energy.

Yabe: Fuji Electric has an impressive track record in geothermal power generation. Actually, an even better solution would be to generate power using warmed cooling water that has been discarded from a factory, but one difficulty would be the long time required to recover the capital investment. In the present era, however, such thermal energy must also be treated carefully, and if we consider whether the thermal energy should be used to generate electric power, or whether its temperature should be raised and then utilized, as well as the sorts of systems that would be able to use this energy, I think that such development would be very profitable.

Eguchi: For geothermal power generation, Fuji Electric has expertise in a flash method that generates electric power using steam extracted from hot water that flows out of the earth. We are using double-flash or triple-flash methods whereby, after extracting steam that is 200 °C or hotter, the pressure of the remaining water is reduced and low-pressure steam is extracted, and after extracting low-pressure steam, the pressure of the remaining hot water is again reduced and the low-pressure steam is used to generate electricity. This method is used at the Nga Awa Purua (NAP) Geothermal Power Station in New Zealand, and was awarded the top prize of the Japan Electrical Manufacturers' Association (JEMA) in 2012. The power generation capacity of a single turbine is 140 MW, which is the largest in the world for geothermal power generation. Recently, we are also advancing practical application of binary generation, which uses low temperature hot water to vaporize low-boiling-point media for use in generating electric power.

Yabe: Geothermal power is the type of renewable energy that is supplied most stably. It is unfortunate that geothermal power generation has not been able to become more popular in Japan. Everyone is now putting forth ideas for ways to use thermal energy more effectively, and I do hope that Fuji Electric continues its efforts in this area.

Eguchi: We want to increase activity in Japan where there is high potential for using geothermal energy. We are also working to spread the usage of geothermal power generation.

Initiatives for distributed energy

Eguchi: By the way, I have heard that AIST is conducting research into distributed energy network technology. Could you please elaborate on that?

Yabe: In the aftermath of the Great East Japan Earthquake, public opinion has increased for using renewable energy as much as possible. In response, AIST established a research center for renewable energy in Koriyama, Fukushima Prefecture. Demonstration testing of various types of renewable energy can be conducted there. We want to use this

facility as a testbed for studying how to handle input energy that fluctuates greatly.

While speaking with victims of the Great East Japan Earthquake, I was told that "After the large earthquake, there was no electricity for about 1 week, but the sun shone brightly. We would have been able to endure the cold only if at least community centers had electricity from solar power generators," and I realized that, separate from the economic issues, an energy system that provides a foundation for an autonomous lifestyle is also essential.

Accordingly, there are still many topics regarding distributed energy to be researched and developed, such as the establishment of energy bases for disaster prevention and techniques for handling a demand response system that uses energy effectively. We want to continue to focus on this field in the future.

Eguchi: Fuji Electric is also participating in the Kitakyushu City Smart Community Project, the centerpiece of which is demand response. A technique known as dynamic pricing, whereby the range of the price for electricity varies according to the temperature forecast for the next day, has been applied and a very interesting result has emerged. As the price of electricity increases, the usage of electric power decreases, and the peak demand for electrical power decreased as a result.

In consideration of such consumer psychology, it is conceivable that when the amount of solar power generation is increased, the price of electricity can be reduced to increase consumption significantly instead of storing that energy. In order to popularize renewable energy, a multi-faceted approach is necessary.

Yabe: As you say, demand response based on economics would also be an important key.

Eguchi: A comprehensively thought-out approach would be good, whereby in addition to an economic incentive to save on energy costs by conserving electricity, there would also be an incentive to help the environment by using clean energy to reduce CO_2 emissions.

Overcoming the "Death Valley"

Eguchi: Now that I think about it, the future of energy technology is often spoken about in the context of its relation to society.

Yabe: I mentioned this briefly before, but AIST's mission is to "bring technology to society," and we believe it to be extremely important that the things we research and develop will be useful to society. However, between the practical research stage and the product commercialization stage, there lies a "death valley" and then during the time until product commercialization and survival in the market, the tests and trials known as the "Darwinian Sea" are waiting.

Let me give an example. One of the inventions AIST is most proud of is carbon fiber. Carbon fiber was invented for the first time in the world in the 1950s by a researcher named Shindo at AIST's Kansai Center. Then in the 1970s, practical applications were realized in the fiber industry by Toray Industries, Inc. and others. Carbon fiber was commercialized and overcame the R&D "death valley," but from the perspective of a corporate operations department, it would be very difficult to enlarge the industrial scope of this invention with subsequent research and development. Fiber manufacturers expanded the market to fishing rods, golf shafts and airplanes, and grew the market to nearly 100 billion yen. This can be called an example of successfully having crossed the "Darwinian Sea."

We have witnessed research and development efforts in many countries, but most of the technology is unable to overcome the "death valley" and ends up forgotten.

What should be done to overcome the "death valley"? I think that a generic methodology might exist. Such a method would firmly identify the best application early on, feed back profitability calculations to the basic research department and focus on important research, and as in the case of SiC, manufacture and send out samples to show the product to the public is also an effective way to have the technology accepted by society. Seeing an actual product tends to make people also want to try and make it by themselves. In order to overcome the "death valley," we also intend to focus on open innovation.

Using roadmaps to evaluate practical research

Eguchi: It is important that researchers pay attention to whether a certain technology is used in society and survives. At AIST, the researchers are made aware of this, aren't they?

Yabe: After becoming an incorporated administrative agency, we have consistently made our researchers aware of this. And finally after 10 years, I feel that everyone's awareness has changed.

For biomass energy conversion systems that use a combination of biological processes and chemical processes to make ethanol from wood, AIST was the first in the world to make trial calculations of the profitability of such a system. That paper received an award at an academic conference, and now everyone has a shared view of the importance of realizing practical applications for technology.

Eguchi: How do you evaluate researchers with regard to their efforts toward realizing practical applications?

Yabe: We call it a roadmap evaluation. The roadmap of each project is drawn to show whether the technology will clear the "death valley" and be accepted by society, whether it is economically feasible, and also shows tasks to accomplish in order to realize practical applications. While looking at the roadmap, we make our evaluations based upon the progress to date.

Eguchi: That is a great approach, especially because basic research tends to lose sight of the exit and is also difficult to evaluate. By all means, please allow us to reference this roadmap evaluation.

Nurturing talent and technology through exchanging information

Eguchi: AIST has various researchers, both male and female, and working both in Japan and overseas, I believe.

Yabe: We have nearly 600 foreign researchers, and have signed comprehensive agreements with various institutions and laboratories throughout the world to create an information exchange network. In the environment and energy field, in order to prevent warming of the entire planet, cooperation with foreign countries is essential instead of efforts limited to Japanese-led initiatives. We are continuing efforts to encourage all countries to come together and establish international standards.

Eguchi: Fuji Electric is also anticipating globalization, and is increasing our number of overseas bases at a rapid pace. However, because our core research is based on Japan-led initiatives, our researchers are recruited and work in Japan, and foreign researchers only constitute a few percent of our total number of researchers. We plan to focus on power electronics as a core technology, and want to hire a broad range of researchers in the field, but I think assembling talent globally will not be easy.

Yabe: A significant portion of the research and development work for power electronics can be advanced by Japan, I think. However, speaking from the experience of having conducted research jointly with a research institute of the U.S. Department of Energy, oftentimes, during a discussion, a previously unconceived thought may arise, and will coalesce into a new idea. Discussing an idea, after having thoroughly thought it through, with a person having a different point of view is an approach to innovation,

and I hope you aim for this because it is an important part of globalization.

Eguchi: As for Fuji Electric, we have established a course in power electronics at the University of Tsukuba. We hope that, by taking this course, the number of young people interested in power electronics will increase.

Yabe: In the summer of 2012, AIST sponsored a 3-day "Tsukuba Innovation Arena (TIA) Power Electronics Summer School," and of the more than 100 attendees, half were graduate students and half were young company employees. Being able to study from the dual perspectives of materials/devices and applications, rather than just from a single perspective as is usually the case, I believe, provided these students with a comprehensive view. Additionally, Vice President Shigekane of Fuji Electric also spoke as a lecturer from the perspective of industrial applications for power electronics. I was impressed that everyone was listening intently with their eyes beaming. I think that this is also a way to cultivate talent.

Ultimately, human resource is important, and if such talented people can be nurtured and raised, then good technology will also emerge.

Eguchi: I agree. As in the case of AIST and the University of Tsukuba, an environment that provides the opportunity to study state-of-the-art technology with teachers and researchers is great. The aim in establishing a power electronics course at the University of Tsukuba is, through cooperation between the university, AIST and companies, to foster future engineers and researchers who have a true understanding of applied technology, from the device level to circuit applications. I think that the individuals who have studied here will play important roles in the future of power electronics.

Yabe: The young researchers at AIST too, while advancing their research and development in an environment where they are able to engage in serious discussions with Fuji Electric personnel, come to understand what is sought now and what are the important points for basic research. This mutual stimulation is beneficial, and I feel that the technology will grow as a result.

Reviving Japan with energy technology

Eguchi: Japanese companies seem to be losing their self-confidence nowadays. This feeling is especially acute among electronics manufacturers. Japan, however, possesses the technology to lead the world

in the field of energy and the environment. Putting that technology into practice would enable Japan to regain its vitality. We would like AIST to use its knowledge to lead us corporations and to direct Japanese technology along the same vector so that ultimately the entire nation of Japan will be revived.

Yabe: It is our dream that, through our TPEC activities, SiC power electronics technology will be introduced to the world, and will spread globally to promote energy savings. We all want to do our best for this purpose. What we can do, however, is to run the organization well to accomplish our mission, and when a technology has ventured into the world, for example, we could address the form of the relevant international standards, or how society should relate to the risks of the technology.

Japan possesses knowledge that can drive the global field of energy and environment. With everyone's cooperation, we want to make this a successful example. Thank you for your ongoing support.

Eguchi: We would like to deepen our cooperation in terms of technology and personnel, and in addition to reviving Japan, also want to contribute to solving global energy and environment-related problems. Thank you very much for your time today.