Over the Century — A Hundred Years for Science, Technology and Mankind

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1. Introduction

In March 1911, just 100 years ago, the Seitetsu Kenkyukai Report—the origins of the Shinnittetsu Giho (Nippon Steel Technical Report)—was published. This was in the early days of the government-managed Yawata Steel, and Japanese steelmaking technology was in its infancy. The report is said to have been published with the intention of prompting the following four improvements [1] :

(1) Introducing advanced steelmaking technology from abroad, understanding the basic principles behind it, and developing new steelmaking processes adapted to Japan.
(2) Resolving the inadequate technological interchange between departments within the works.
(3) Re the above, enhancing the spirit of cooperation among factory workers under the management's leadership.
(4) Pursuing continual improvements during routine operations.

Although the report was published a century ago, the concepts underlying it are by no means old-fashioned. The matters pointed to in the report remain as valid today as they were then. Imagine, for example, an organization consisting of many highly independent departments/sections, like an integrated iron and steel works. If those departments/sections are so closed off to one another that it prevents smooth communication between them, it is essential to break out of that status to enable smooth communication. Concerning the transfer of specific technology, it is indispensable not only to study the technology, but also to understand its essence and adapt it to actual domestic conditions. Furthermore, it is important to make continual improvements in day-to-day operations.

The Seitetsu Kenkyukai Report was launched by 16 voluntary assistant engineers, whose basic stance was "not to cause any nuisance to their department/section managers". Their spirit of independence was manifested when they opposed the proposed merging of the Report with the "Tetsu-to-Hagané" journal when the Iron and Steel Institute of Japan was established in 1915. At that time, they showed their resolve in establishing their own research organization and pursuing research on their own. It is especial noteworthy that the Seitetsu Kenkyukai Report started out as a tool for field researchers to express their keen awareness of the problems they faced and their strong will to tackle them.

The first research institute in Japan's steel industry was founded within the government-managed Yawata Steel in 1919. At that time, Susumu Hattori, the first director of the Institute, described the philosophy of the Institute as follows [2]:

"The objective of the Institute is to study matters that help with the improvement or progress of operations of the Works and to work in close cooperation with the plants at all times so as to unite theory and practice and thereby to promote the development of technology".

It is praiseworthy that as far back as 100 years ago, he cited "uniting theory and practice" and the resulting "development of technology" as the main objectives of the Institute. On the other hand, it is a remarkable historical fact that the Seitetsu Kenkyukai Report—a periodical planned and published by middle-class workers—predates the foundation of the Institute.

Looking back to the forefront of theoretical research in the world about a century ago, " 1905—the Year of Miracles" occurred to me as a key phrase. In 1905, Albert Einstein announced five papers [3].

March paper : Photoelectric effect; quanta of light energy with particulate qualities; revolutionary paper on quantum theory, candidate for a Nobel Prize
April paper : Liquid viscosity + diffusion; atomic theory that assumes atoms as the base of the material world; Einstein's thesis for a degree
May paper : Brownian motion; atoms, statistical fluctuation, and statistical aspects of thermodynamics
June paper : Special theory of relativity; fusion of time and space
September paper : Equivalence of mass and energy; $E = mc^2$

It is interesting to note that about 100 years ago, the subjects of atomic theory and quantum theory were hotly debated and that the special theory of relativity was presented in almost perfect form by a genius (Einstein himself denied he was not one). I just cited the above five papers of Einstein to given an example of how theories were built in those days. It is interesting to know, from the standpoint of science and technology, that the theories discussed in the five papers have already been united with practices in diverse fields, thereby promoting the development of technology.

2. Age of Progress, Diffusion and Complexity

In about a century, since the hotly debated atomic theory and quantum theory, science and technology has made extraordinary progress. Today we are in the age of nanotechnology. In 1911, just one hundred years ago, Kamerlingh Onnes discovered superconductivity—the phenomenon whereby electrical resistance

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becomes zero not at absolute zero, but at a finite temperature. This is an interesting phenomenon in that the quantum effect can be observed as a macro-system. Since that time, many remarkable advances have been made in science and technology. For want of space, only representative examples are shown in **Table 1** [4].

Table 1 is a very rough list of scientific discoveries considered relevant to materials only. Even so, it is very interesting to note that a good number of discoveries sprang by chance from well-planned experiments and that the new theories and methods of observation have helped advance the frontiers of science and technology. The individual discoveries and inventions more or less reflect their contemporary historical background. On the whole, I strongly feel that they are related to one another in their contemporary society.

Looking back on the past over a longer time axis, it seems that various scientific and technological achievements and practical products have evolved through stimulation of one another (**Fig. 1**). The practical need to measure blast furnace temperatures gave rise to the concept of action quantum, a concept which led to the quantum theory. The discovery of wave-particle duality of electrons and the invention of an electron microscope made it possible to discover viruses and carbon nano-tubes in the field of science, and experiments on quantum phenomena using an electron microscope helped advance the quantum theory. On the other hand, the progress of various analytical techniques, including the electron microscope, supported by materials technology, has resulted in both scientific and technological contributions in diverse fields of society. Thus, it seems that theory and practice attractively tie up from time to time.

As an example of technological progress, the results of observing fluxons of a high temperature superconducting material are shown in **Fig. 2** [5]. In studying the properties of the high temperature superconducting material as a practical material, the interaction between fluxons and their pinning center becomes key. The progress of electron microscope technology has at last enabled direct observation of the quantum effect that had long been discussed. This fact should have a great impact on the development of new materials. The example given above is one in which analytical technology and materials technology progressed while interacting with each other.

As an example of the ultimate observation applying to nanotechnology, **Fig. 3** shows the results of the world's first

Table 1 History of science and technology related to materials [4]

Year	Researcher or discover	Scientific discovery or invention
1911	Onnes	Discovery of superconductivity
1925	Lilienfeld	Principle of field-effect transistor proposal
1932	Knoll and Ruska	Electron microscope invented
1948	Bardeen, Brattain and Shockley	Bipolar transistor invented
1950	Inokuchi	Organic semiconductors discovered
1953	Watson and Crick	DNA structure discovered
1957	Bardeen, Cooper and Schrieffer	BCS theory proposed
1959	Kilby and Noyce	Integrated circuit (IC) invented
1967	Dennard	Dynamic random access memory (DRAM) invented
1969	Fujishima and Honda	Photocatalysis discovered
1970	Esaki	Semiconductor superlattice concept proposed
1975	Spear and Le Comber	Amorphous silicon p-n junction created
1976	Endo	Carbon nanofiber formation discovered
1977	Shirakawa	Intrinsically conducting polymer discovered
1980	Klitzing	Quantum hall effect discovered
1982	Binning and Rohrer	Scanning tunneling microscope (STM) invented
1985	Kroto, Smalley and Curl, et al.	Fullerene discovered
1986	Tonomura	Aharonov-Bohm effect demonstrated
1986	Bednorz and Müller	High-temperature superconductor discovered
1987	Chu and Wu	Yttrium-based high-temperature superconductor discovered
1988	Maeda	Bismuth-based high-temperature superconductor discovered
1990	Rose	Aberration correction of electron microscope
1991	Grätzel	Dye-sensitized solar cell proposed
1991	Iijima	Carbon nanotubes discovered
1994	Tokura et al.	Colossal magnetoresistance discovered
2004	Geim and Novoselov	Graphene successfully isolated
2008	Hosono	Iron-based layered superconductor discovered

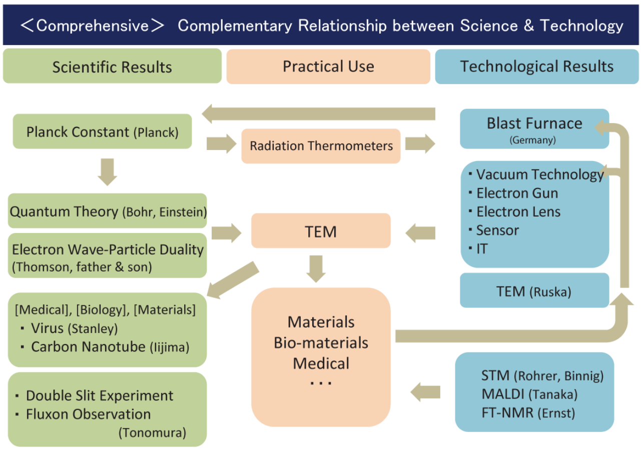

Fig. 1 Example of complementary development of science and technology

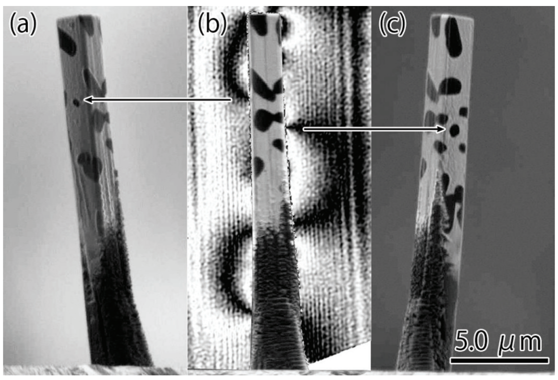

Fig. 2 Electron holography demonstrates fluxon trapping in the 211 phase of a QMG® superconductor developed by NSC
This photograph clearly proves the basic theoretical aspect of fluxon trapping [5]**.**

observation of hydrogen in steel using a 3-D atom probe [6]. It can clearly be seen that hydrogen has been trapped at the interface between iron and the precipitate. Thus, atomic theory—which was hotly debated about 100 years ago—has come to be applied to research on practical steels.

We have so far briefly reviewed the progress of science and technology over the past century. What then is the present age like? In order to answer that question, I can cite various keywords—the environment, resources, energy, population explosion, population shrinkage, and the North-South divide. The age of mass production → mass consumption has already changed in pattern into mass collection → mass production → mass consumption → mass waste disposal. The long-held 'infinity illusion' has been shattered. Now we cannot but recognize the finality of our society as a system having both a starting point and an ending point [7].

On the other hand, modern society is in an age where information is exploding and overflowing. **Fig. 4** shows the change in annual volume of information distribution in Japan [8]. It should be noted that the vertical axis uses a logarithmic scale. As shown, the volume of information that users have access to has been expanding exponentially. By comparing that volume with the volume of information that is actually used, it can be seen that the volume of information supplied is far larger than the volume of information actually used. Needless to say, that explosion of information is a result of the progress of computers, the spread of the Internet, the increased means of personal data communication (e.g., blogs, SNS and video distribution services), etc. The implication is that information society has changed into 'esurplus information society' to the detriment of that information's value [9].

The finitude of resources and waste disposal extends beyond the controllable limit to such a degree that it is indispensable to optimize the environment, resources and energy as a system. For example, the electricity power network, or the grid, which is one of the most important means of energy supply, is now required to respond flexibly to renewable energies that are essentially of a non-steady character. Under that condition, it is an urgent necessity to build a smart grid that takes into consideration the uncertainties of electric power generation and electric power consumption. The problem of optimization of such a system cannot be solved by conventional linear programming techniques. **Fig. 5** shows the necessity of developing a new mathematical technique to deal with that problem [10]. In the future, it will become increasingly important not only to consider optimizing the existing infrastructure, but also total optimization of the wider scope, involving, for example, industrial plants and the local community. In this context, developing an effective mathematical technique is strongly called for.

As described above, the scope of control we have to handle has become wider and more complicated than ever before, and the amount of information itself that must be handled for total optimization is about to explode. Under the double torture of an explosion in supplied information and expansion of the scope of information that must be handled for total optimization, it will become indispensable in the future to enhance system controls utilizing mathematical techniques, etc.

With the accelerated globalization of Japanese industry, in building production bases overseas, it will become indispensable to deal with the problem of optimization not only for planned production plants, but also for conditions other than location, such as the local environment, electric power supply and water supply. Without positively responding to that problem, implementation of globalization is impossible. In this context, it is recognized that modern society has entered a phase in which it is important to build totally optimized production bases with due consideration for their influences on the biological environment and ecosystems in their localities. **Fig. 6** shows an example of biological experimentation conducted to demonstrate the effectiveness of using slag in marine areas [11], which is considered a promising material for regenerating seabeds. This demonstrates that iron ions are a key factor in the regeneration of seabeds. It has become important to accumulate the results of basic research, like the example shown above.

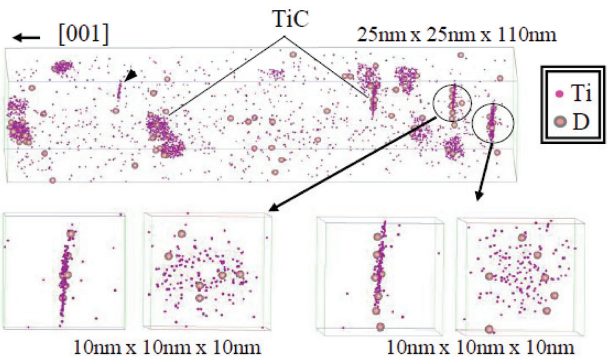

Fig. 3 3D-AP demonstrates hydrogen atoms trapped at the surface of the plate-shaped precipitate
The first observation of hydrogen trapping using 3D-AP was achieved by NSC's extensive R&D efforts [6].

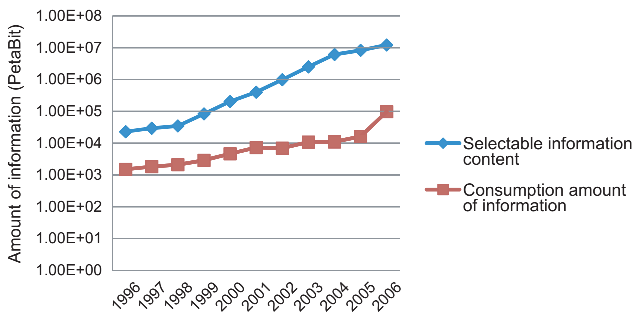

Fig. 4 Chronological transition in the amount of information distribution [8]
Selectable information content: The total amount of information offered in a format which the information consumer can choose within one year at the data reception point of each media.
Amount of information consumed: The total amount of data which the consumers actually received and consumed in one year via each media.

3. Looking to the Future

In the preface to his book "Materials and the Environment" [12], Michael F. Ashby writes as follows. The passage is rather lengthy, but let me cite it here because it admirably expresses the present situation.

"The environment is a system. Human society, too, is a system. The systems coexist and interact, weakly in some way, strongly in others. When two already complex systems interact, the consequences are hard to predict. If we are going to do anything about it, the first step is to understand the origins, the scale, the consequences, and the extent to which, by careful material choice, we can do something

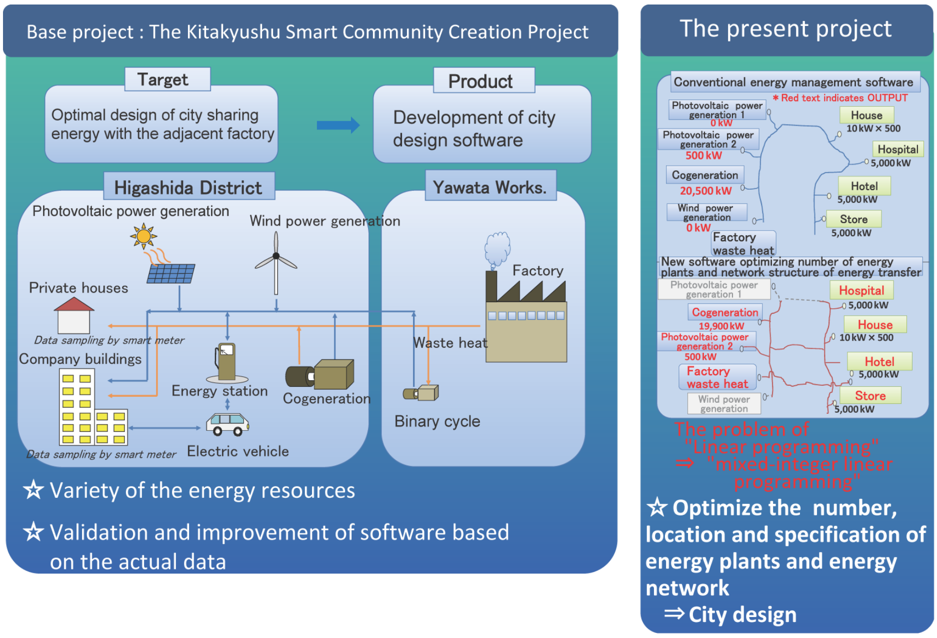

Fig. 5　Example of NSC's activity related to the KitaKyushu Smart Community National Project NSC is now developing a sophisticated mathematical analysis method [10].

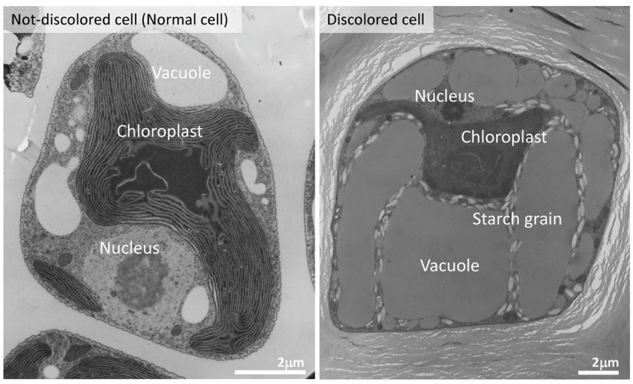

Fig. 6　Effect of ferric ions on the growth of kelp, an edible seaweed used for Japanese "nori" [11].
These ions are essential for seaweed to grow normally.

about it. And that requires facts".

Materials that are important constituents of our society can no longer exist by themselves. They exist for human society in the beginning. On the other hand, materials interact, directly and indirectly, with the environment, which further interacts with human beings. In order to create an affluent society, it is indispensable to recognize the scope of the above interaction and optimize all the systems involved in it. The world has become so complicated that the span of space that must be handled has expanded to a global or even larger scale. On the other hand, with the increase in volume of information and the decline in value of information, our society is becoming more complicated faster than ever before.

We must act in perspective, and there is a ray of hope here. Namely, this Centennial Commemorative Issue contains many of the products, mainly in the field of materials, which Nippon Steel Corporation has produced so far. Although it focuses on the company's activities, I believe that materials technology will, together with science and other fields of technology, continue evolving and become more friendly to the environment. The problems to be solved have very large dimensions. On the other hand, the means to solve them are abundant. Nippon Steel Corporation has many different materials as a result of many years of research and development—steels, aluminum, titanium, ceramics, polymers, carbon, semiconductors, packaging materials, and composite materials. By applying them in combination with such sophisticated disciplines as the analytical, mathematical, computational, environmental, biological, interfacial and system sciences, coupled with the company's production technology cultivated over 100 years, and through industrial-academic cooperation, I believe that Nippon Steel Corporation will be able to contribute much even to a highly complex society in the future.

Research starts with people and researchers. Sanichiro Mizushima, the first director of the Tokyo Laboratory of Yawata Steel, made the following remarks [13]:

"A professional who is free from professional consciousness is a researcher worthy of respect... It is important that researchers who toil and moil are able to see the realities as they are ... Every parent wants their children to enter a good school. Good teachers, fine facilities? There are things that seem more important to me. The essential merit of a good school is the opportunity to make good friends, who study hard together to cultivate their character. The respectable traditions of a prestigious school may be attributable — at least in part — to the character of the head of the school. In my opinion, however, the presence of a group of good students is the most important attribute of a good school. The same applies to a good research organization: the most important thing is that it has a group of people who know the essence of research".

This Centennial Commemorative Issue contains that important essence of Nippon Steel Corporation. In our complicated society, now is the time when the intense problem consciousness and interdisciplinary activity displayed by those 16 assistant engineers who initiated the Shinnittetsu Giho 100 years ago should help to contribute to the progress of technology, with the aid of new theories in mathematical science, etc. and the practice of those theories.

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