Open foundry to spur open-innovation

— Establishment of a foundry to realize an innovative cooperation platform and development of its sustainable management strategy —

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Open foundries enable us to share cutting-edge equipment with global partners of industry-academia-government collaboration, and to promote interdisciplinary integration and job mobility among research personnel. Foundries have been established in many world-class public organizations, and are widely recognized as one of the most effective measures to spur R&D open-innovation. In this paper, the management strategy of the AIST open foundry, the Nano Processing Facility, is discussed. In this foundry, cooperation with users brings about the integration of R&D achievements and technologies. This paper also presents a scenario for sustainable development of the foundry as an eco-innovative cooperation system.

Keywords : User foundry, interdisciplinary integration, human resource development, open-innovation, global cooperation platform, eco-innovation

1 Introduction – What is an open foundry?

To promote R&D efficiently, a facility where researchers can share state-of-the-art devices and equipment and utilize its prototyping capabilities is important. In the 21st century when the economy is globalizing rapidly, the necessity has increased to progress from R&D to technological development to commercialization, or to quickly transfer the research topics from the site of production to the site of R&D.

Today, R&D that must be done by a corporation and the space in which businesses are conducted have increased. With such a background, an open foundry, or a common-use facility to share the state-of-the-art equipment, will function as an engine to shift the vector outward and open up space for the companies that harbor inward-pointing vectors, as they seek research and technological developments within themselves and spend effort to build a mechanism only in closed space. Since nanotechnology is a core technology that cuts through an extremely wide range of research disciplines, a foundry will contribute greatly to various industries. The foundry will allow the universities and public research institutions to avoid owning expensive state-of-the-art equipment, and thereby allowing them to efficiently manage their limited budget and to be able to promote interdisciplinary integration via the foundry.

The open foundry in nanotechnology R&D of the United States will be discussed. The National Nanotechnology Initiative (NNI) positions the R&D infrastructure of public institutions as the target of continuous budget allotment, and over 10 % of the total NNI investments are allotted to this target.[1] The characteristic infrastructures were built at the National Nanotechnology Infrastructure Network (NNIN) of the National Science Foundation (NSF), the Nanoscale Science Research Center (NSRC) of the Department of Energy (DOE), Center for Nanoscale Science and Technology (CNST) of the National Institute of Standards and Technology (NIST), and others. In the report that describes the policies and results of the NNI and the issues and guidelines for the year 2020, it is explained that “these facilities must be expanded to provide prototyping capabilities that will accelerate the transition of research discoveries into innovative technologies.”[2] Also, further organization and advancement of the foundry function are positioned as one of the most important topics for the 2020. The reason for setting this as the most important topic is that “without (user facilities providing prototyping capabilities) facilitating the transition of science/engineering discovery into innovative technologies, continued support for nanoscale science and engineering may be jeopardized.”[2]

In this paper, first, the types and functions of the foundries operated by the public institutions, and the dilemma in managing them are explained. Next, based on the analysis of the current status of the foundry managed by AIST, the scenario for the continuous growth of the foundry, and the scenario for realizing eco innovation (a sustainable innovation system) that continuously widens the space for innovation spurred by such foundry will be presented.

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2 Types, functions, and issues of the open foundry

2.1 Categorization of the open foundry[1]

There are a number of representative types of open foundries. The foundries are categorized from three viewpoints.

2.1.1 Type in which large equipment is shared and type which aggregates multiple equipment

The examples of foundries that share ultra large experimental equipment include the Super Photon Ring-8 GeV (SPring-8) and the Beam Line of the High Energy Accelerator Research Organization (KEK or Ko Energy Kasokuki Kenkyu Kiko) in Japan, and the Los Alamos National Laboratory in the United States. There are many relatively expensive equipment in the nanotechnology field, and the ultra high-voltage transmission electron microscope, for example, is shared in the similar managerial format as the foundry for large equipment. On the other hand, there are facilities that are very attractive to users because equipment, even if it consists of general-use, small/medium-sized equipment, is aggregated in one place. The foundries that are offered for open use by universities, such as the facilities participating in NNIN in the US, can be categorized as this type which aggregates multiple equipment. The centers with large exposure equipment along with the peripheral general-use equipment related to semiconductor technology, such as the Albany Nano Tech Complex in the US, IMEC (formerly, the Interuniversity Microelectronics Centre) in Belgium, MINATEC (formerly, the Micro and Nanotechnology Innovation Centre) in France, and the super clean room facilities at AIST can be positioned as the intermediate type of this category.

2.1.2 Central type and network type

The aforementioned large equipment sharing foundry, the National Nano Fab Center (NNFC) of Korea, Korea Advanced Nanofab Center (KANC) also of Korea, and Institute of Microelectronics (IME) of Singapore can be categorized as central facilities that attract users by aggregating large equipment within their compounds. On the other hand, the foundries participating in the NNIN of the US and the foundries of the public institutions participating in the Nanotechnology Platform Project[3] of the Ministry of Education, Culture, Sports, Science and Technology (MEXT) of Japan can be categorized into the network type that aims to provide complementary research support services.

2.1.3 Type for accumulating/integrating knowledge and type for strengthening industrial competitiveness

The Center for Integrated Nanotechnologies (CINT) that is part of NSRC is a facility established under the national policy to accumulate knowledge, to integrate accumulated knowledge, and then to create new knowledge. The users who publicize the results are not charged, and its primary index of evaluation is to gather as many users as possible. Compared to the facilities where users are charged because they are considered beneficiaries, it is categorized as being at the opposite end, from the perspective of the way in which the foundry is managed. On the other hand, the type of foundries for strengthening industrial competitiveness charges the users as they are deemed beneficiaries, and the results are unpublished in many cases. When a facility is established to solve a specific issue, it may be called a problem-solving foundry.

2.2 Functions and roles of the open foundry

The open foundries have functions and roles characteristic of the categories described in subchapter 2.1. In this subchapter, the roles and functions are broken down into five categories, and what are expected for each category is explained. In this paper, “science” and “technology” are separated, and “research” and “development,” are considered actions with different vectors. Of the open foundries, it will be easier to understand the functions, particularly for the type for strengthening industrial competitiveness, by clarifying the differences between research and development (Fig. 1).[4][5]

(1) Promote interdisciplinary integration

In the type that concentrates/integrates knowledge and the central type foundries, the interdisciplinary integration is promoted through the gathering of researchers with different specialties and through new relationships being built among them. The formation of new relationships is the origin of innovation, and is the primary function of a foundry where diverse people and knowledge gather.[Note)]

(2) Promote mobility of research results

For the production of knowledge, the involvement with various players is necessary, including not only researchers but also engineers, students, as well as salespeople who are not necessarily involved in R&D. Knowledge has a package-like characteristic that is born from such congregations.[6] In the foundry, the knowledge package is produced in the process of development where the research results are sifted and selected, as shown in Fig. 1. On the other hand, in the technological development phase shown on the right side of the figure, it is not easy to transfer the knowledge package outside for practical use, and it is important that a foundry where many types of players reside functions as a trading zone.

(3) Strengthen capacity to handle complexity and uncertainty

One of the purposes of NSRC of the United States is to strengthen R&D capabilities to handle a totally new issue, and it is equipped with the function to handle the complexity of R&D and the uncertainty of innovation. Particularly, the foundries that aggregate multiple equipment and those that concentrate/integrate knowledge are operated for the purpose of strengthening the capabilities to handle such complexity and uncertainty.

(4) Provide complementary technology

The universal role of the open foundry is to respond to the requests from diverse and wide-ranging users and speedily provide solutions. Particularly, an open foundry that is networking with multiple user foundries is expected to provide efficient research support by offering complementary technology in its field of specialty.

(5) Promote human resource mobility

When a researcher wishes to start up new research when moving from one workplace or section to another, there are major time and financial barriers. These can be reduced by using the open foundry, and the mobility of young researchers will be promoted. Therefore, in NNIN and the Nanotechnology Platform Project, the participating open foundries are selected with their locations also considered.

2.3 Dilemma of managing an open foundry

I shall introduce one of the major managerial dilemmas faced by many open foundries in Japan. For a public institution, financing the maintenance cost of the expensive state-of-the-art equipment is one of the major problems. Therefore, in many cases, idle time of the state-of-the-art equipment is loaned to R&D of external researchers, and the income from the charges collected are used for equipment maintenance. As a result, a user foundry that claims the efficient use of expensive equipment by using it for its own R&D as well as sharing with others is established. On the other hand, if the efficient use of idle time is thoroughly enforced, the priority of cost reduction increases excessively, and this may lead to (1) reduced cost of labor, (2) elimination of support for R&D with a large number of process steps, or (3) keeping away from difficult R&D topics. Moreover, in cases where the institution to which the foundry belongs or the institution that provides financial support considers the users as the beneficiaries, establishes and strongly enforces a charge system, the demand for cost reduction will increase on the side of the user. In an environment with strong cost reduction demand, the facilities and equipment that are used for a long time degenerates and aging is accelerated, and the “tragedy of the commons” occurs.[7][8] The users are less attracted to worn out facilities and equipment, and as a result, the idle time increases. Unless equipment sharing becomes the main business, a user foundry cannot gain profit from equipment sharing, and meets the dilemma that rational management does not lead to strengthened management. The share use of idle time is one of the choices for cost reduction, but it must be noted that such cost reduction possesses the aspect of depleting provided services.

3 Open foundry of AIST

3.1 Three open foundries and their collaborative system

At AIST, there are two open foundries in operation with over 10 years of history. They are the Super Clean Room (SCR) of Tsukuba West and the Nano Processing Facility (NPF) at Tsukuba Central 2. Also, as a problem-solving type foundry, the Platform for Green Functional-Oxide Nanotechnology (GreFON) stands next to NPF.

SCR is an open foundry with the characteristics of the type that shares large equipment and that which aggregates multiple equipment. It consists of a 3,000 m^2 super clean room (JIS Class 3) with a process line for 12-inch wafers, and a 1,500 m^2 research clean room (JIS Class 5) with a process line for mainly 4-inch wafers.

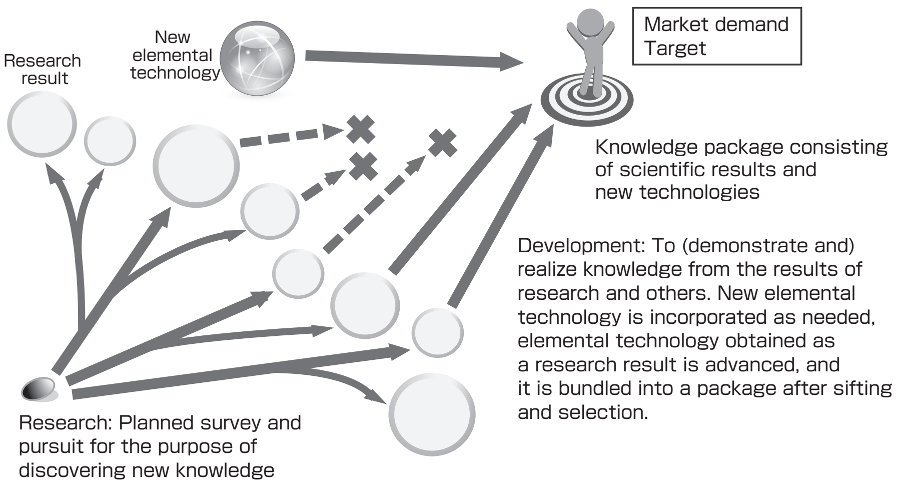

Fig. 1 Difference between research and development

A research has a divergent vector where all the circles may become results, including the arrows that were unexpected initially. On the other hand, a development has the vector of sifting and selecting the research results and then gathering them up as a knowledge package matched to the market demand. Previously, research and development were in a linear relationship with overlaps in several areas, and if a technology was good, it could be connected with a solid line. Currently, research and development must be clearly delineated to generate new values. Often, a totally new elemental technology is necessary.

NPF has the characteristics of the multiple equipment aggregating type and the network type. By collaborating with the Nanotechnology Platform Project and GreFON that were introduced earlier, it is managed for both the functions of the type that concentrates/integrates knowledge and the type for strengthening industrial competitiveness.

Recently, there has been a rapid increase of users who utilize these open foundries according to their R&D phases, such as using SCR for the application of new materials developed at NPF or GreFON to the large-scale integration process technology, or conducting elemental technology development at NPF to resolve the R&D bottleneck at SCR. Since pages are limited in this paper, focus will be placed on NPF for further discussions.

3.2 Nano Processing Facility

The Nano Processing Facility (NPF) was initiated as a user foundry for research units within AIST in April 2001. Initially, it consisted of a 231 m^2 clean room. In the press release for its launch, it is stated, “This is a facility to be shared by researchers of electronic engineering, optical engineering, molecular engineering, and biotechnology, under the motto of ‘expeditious realization of ideas.’ The objective is to pioneer new industries by integrating the creativity of the individual researchers and by producing nanotechnology products that is the hope of the 21st century, through the R&D of next-generation information devices, ultra high density optical recording, molecular devices, and sensors.” It was managed with the cooperation of seven research organizations mostly within AIST, led by the Nanotechnology Research Institute. Efforts were spent to organize and manage the facility and a support system that enabled the formation of structures at micro and nanometer level needed by the research organizations of AIST, at high throughput, with excellent reproducibility and uniformity, and without having the researchers of wide-ranging specialties to feel the barriers. As a result, there were over 100 users within AIST by April 2003. Although the Nanotechnology Research Institute took the lead for its management, the basic policy from the beginning was to serve as the crossroad of researchers while the institute devoted itself to be the supporter, and care was taken to make access to the state-of-the-art equipment at the foundry fair for all users.

Currently, NPF has developed into an open foundry with a 600 m^2 clean room from Class 100 to 10000 (US federal standard), a 300 m^2 of general experiment facility, and accommodation space for short-term stay of users. It has been commissioned to conduct MEXT research support projects from 2002 to present, and is now promoting operations as a foundry with the functions of accumulating/integrating knowledge and strengthening industrial competitiveness. As of the end of FY 2012, there were over 1,200 user registrations, and about two-thirds were people from outside of AIST. There are a total of about 50 instruments worth several million to several hundred million yen, and there are, on average, about 100 cases of project support conducted per year. It supports joint research with various private companies that are promoted by AIST, and also participates in the Tsukuba Innovation Arena Project.[9]

The NPF forms a user foundry network in Japan, using the subcontract projects of MEXT. For example, it halted operations for about four months after the Great East Japan Earthquake. During this downtime, the corporate users were referred to the foundries of the universities in Tokyo that had similar equipment as NPF, to minimize the delay in the users’ R&D schedule. Maintaining such resilient R&D operations by overlapping some of the functions of the foundries is an important role of the network type foundry that provides complementary technology.

At NPF, generous support is offered to each and every user, including the technological support to strengthen working examples for patent application and the support in creating documents in response to peer reviewers of academic papers. “Support for Success” is the NPF statement that states that action must be taken keeping in mind that the priority is the user’s success and that the success of the NPF personnel is the user’s success. As a result, compared to other user foundries in Japan of a similar scale, NPF has higher percentage of corporate users.[10] An example of R&D support for a private company actually done by NPF is shown in Fig. 2. A request for prototyping was received from a user, the process engineer of NPF developed a new process, and the know-how was accumulated at NPF. The corporate user may bring high-risk research topics to NPF, and in many cases, the results may be “the clarification that the issue cannot be solved by the initially planned process.” This is an example where the user handles the complexity and uncertainty of R&D with minimum investment.

4 Analysis of the current status of the open foundry NPF and the concept of global innovation platform

In this chapter, the current status of NPF that has the highest number of registered users among the open foundries managed by AIST is analyzed. Using the analysis result, the strategy for creating a global innovation platform where NPF can gain new users and continue to grow will be described.

4.1 Analysis of the current status of NPF and the management strategy

To understand the current status of NPF, we conducted the SWOT analysis. The reason for selecting the SWOT analysis is because it allows analysis under the clear strategy of presenting to the users the differentiated value for using NPF, on the boundary condition of not aiming for cost leadership where the base of competition is low cost. In the background is the situation where similar user foundries are increasing and commercial facilities that conduct foundry business are beginning to appear. The result of the SWOT analysis is shown in Fig. 3. The partition between the internal and the external environment was placed on the boundary line between the inside and the outside of AIST, and the categorization was based on whether AIST could directly control the content or not.

In an ordinary clean room, it is necessary to thoroughly reduce the presence of impurities and fine particles of alkali metals or heavy metals that may affect the performance of electronic devices. Therefore, the introduction of new materials that hold the danger of introducing such impurities into the clean room must be regarded with extreme care. However, as apparent in STRENGTHS, NPF greatly succeeds in lowering the barrier of introducing new materials by devising ways for equipment operation, thereby enabling both R&D of electronic devices and new materials. Also, looking at each item of the SWOT analysis based on the goal of differentiating the value of using NPF, it becomes clear from the cross analysis of STRENGTHS and OPPORTUNITIES that the conclusion implied is to select the strategy of gathering users particularly from the materials and equipment manufacturers and to aim to become a facility where users of more diverse industrial fields will gather.

Next, based on the SWOT analysis, we clarified the strategies that should be further taken by AIST. The SWOT analysis

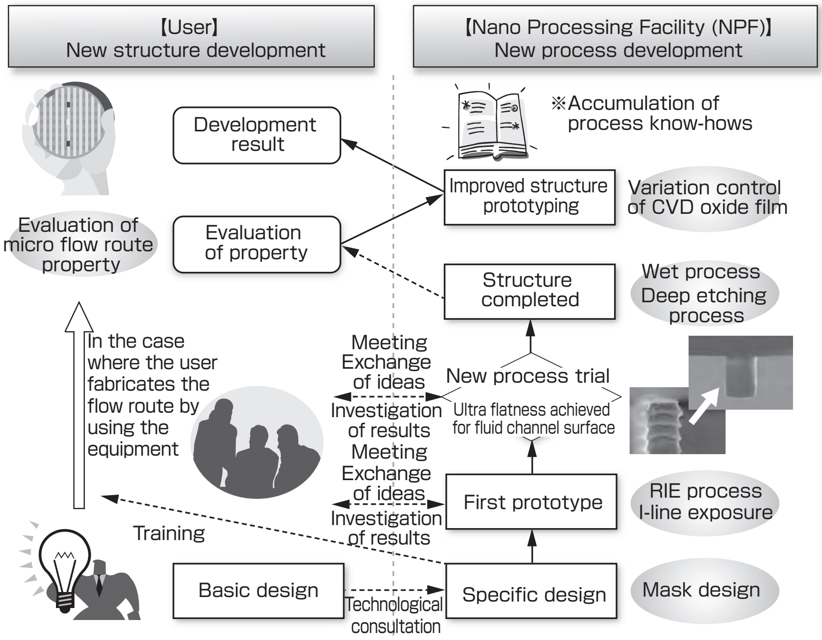

Fig. 2 Example of R&D actually conducted at NPF

NPF received a prototyping request from a user who wished to develop a microfluidic device, but the device with desired characteristics could not be fabricated using the standard process. Therefore, an etching process was developed. Prototyping was successfully done by developing an oxide film forming process that achieved both the variation control and the ultra flatness of the fluid channel surface.

Internal environment	STRENGTHS ・Accumulation of various R&D projects Over 1,000 registered users ・Globally advantaged research topics Technologies for functional oxides (GreFON) ・New materials can be introduced easily ・Excellent engineers ・Abundant technological training program ・Readily accessible to AIST resources	WEAKNESSES ・Limited operation time of clean room ・Lack of available space in clean room ・Aging of equipment for core processes ・Frequent equipment troubles ・Lack of machine time ・Facility operation/Regulated budget execution ・Technology accumulation system not built ・Technology succession system not built ・Technology transfer system not built
External environment	OPPOTUNITIES ・Multitude of collaborating foundries ・Increased consciousness for equal division of labor in managing the foundries and R&D ・Efficient use of research resources by sharing the facilities Increased consciousness for reducing the cost of facility maintenance and saving energy ・Presence of strong manufacturers of materials and equipment in Japan	THREATS ・Newly participating organizations and facilities to the nanotech foundry business ・Transfer of R&D centers overseas

Fig. 3 Result of the SWOT analysis for NPF

is done by placing a divider between the external and internal environments. Therefore, as a method for creating the strategy, we employed the competitive strategy theory where the strategy is considered by separating the origin of innovation into the internal and external areas.[11] The result is shown in Fig. 4. In the upper left corner, the resources within NPF were observed for the resource approach, and the strategy to strengthen the resource itself was proposed. In the SWOT analysis, of the WEAKNESSES, the need for building a technological succession system was derived. The WEAKNESSES are marked by “▼” in the figure. Similarly, in the learning approach in the upper right corner, the investigation shifts to the process of how to overcome the weaknesses. For this, from the perspective of utilizing the STRENGTHS, we obtained the action item of disclosing the information of the technological know-how accumulated by the process engineers to the users. On the other hand, in the positioning approach, the strategy to position NPF to bring out the strengths of NPF is considered. For this approach, a long-term consideration was necessary such as fortifying the linkage between NPF and the production centers. If NPF becomes attractive to the manufacturers of devices, materials, equipment, and fabless, it will become possible to lower the mobility barrier in the users’ business as an open foundry.

The open foundry is a place where both the users and AIST create values. From the viewpoint of the user, the foundry should increase the total amount of value, and even so it will not be attractive unless the user can take the larger share. Therefore, the game approach that NPF must take is the strategy of obtaining new users by creating a good situation while appealing to the external environment including the users. While NPF does not have the facilities that allow semiconductor process development, it has many users of device manufacturers that conduct elemental technology development. Therefore, for example, if NPF can function as an R&D partner of a material manufacturer, the range of the stakeholders including NPF will expand, and the device manufacturer will be able to increase the options of ways to use NPF. Moreover, using the strength that many researchers from multiple companies are engaging in R&D at NPF, if the international standardization of the results obtained at NPF can be done actively, the usage of NPF in the role of a game changer can be proposed to the users.

4.2 Scenario for building a global innovation platform at NPF

Using the strategy established in the previous subchapter, a scenario for making NPF into a tool for promoting further advanced R&D will be explained. In constructing the scenario, we set up the hypothesis that a global innovation platform that will be explained below will grow if NPF employs the game approach. Seen from the viewpoint that the user foundry operation must be carried out while harboring the dilemma described in subchapter 2.3, it will be possible to write an *aufheben* type scenario.[12] At NPF, there are many instances of breakthrough type R&D.[13] However, due to the space limitations of the paper, we describe the scenario for building space for a global innovation platform with NPF at the core and for continuously expanding the space. The scenario for promoting eco innovation is shown in Fig. 5. What the authors have done in the past 10 years was to organize the rules of the foundry and research support, and this corresponds to the organization of the interior of the rectangle marked NPF in Fig. 5. NPF has become an innovative platform called the open foundry, and has built collaboration connected with other foundries in Japan and overseas. On the other hand, by promoting the game approach shown in Fig. 4, NPF creates new users by advancing the provided services and by strengthening the ability to provide services by utilizing its network. The

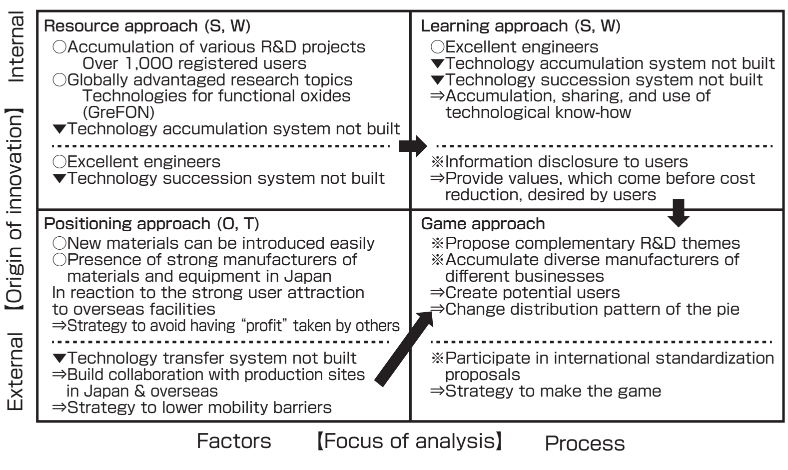

Fig. 4 Strategy analysis matrix for NPF based on the SWOT analysis (Fig. 3)

The process for establishing the game approach to differentiate NPF utilizing the STRENGTHS in the SWOT analysis are shown by black arrows. In the figure, the action items to overcome the WEAKNESSES (▼) that were not mentioned in the text are shown.

newly created users bring in new research potentials to NPF, and NPF incubates such potentials and hands them over to the partner companies and users, thereby further advancing the provided services. Through such positive feedback, the innovation platform with NPF at its core expands beyond the framework of NPF, and the continuously growing global innovation platform is built. In this scenario, the global innovation platform where NPF builds and advances the knowledge package and then hands it over to the user is expanded outward by new users, and grows hierarchically by taking in the partner companies and the business space of the foundries in Japan and overseas. Therefore, this growing global innovation platform is named the eco innovation R&D system from the viewpoint of seeing the foundry as a tool for promoting R&D. As mentioned earlier, the use of open foundries as R&D tools has become common in the last 10 years, and the manner of R&D has changed greatly as the foundries constructed a network. For example, the R&D system itself has changed as exemplified by the stakeholder comments: “The researchers and engineers are freed from the work of equipment maintenance, and therefore can utilize the limited time effectively,” or “The technological potential necessary for R&D can be efficiently gained at the foundry.” The author believes that by widening the global innovation platform through this eco innovation R&D system, an “open foundry that is a place to promote social acceptance (including the improvement of scientific literacy) of the R&D results”[2] can be realized.

Here, a detailed explanation for the eco innovation R&D system and its issues will be given from the perspectives of “advancement of provided services” and “user creation.” First, the “advancement of provided services” cannot be promoted simply by technological advancement. For example, even technological know-how developed at a foundry for strengthening industrial competitiveness, such as product development using a new technology, will be caught up easily by others, if the know-how can be easily transferred so long as the same equipment is available at the institution that dispatched the user. Therefore, to develop a knowledge package that is the union of various technological know-how at the foundry, and then to transfer it to the production center as needed is far more efficient for the user, in terms of time investment from the perspective of avoiding excessive R&D competition. Moreover, if the packaging is done to maximize the profits at each level of design, manufacturing, and setting, after setting the business target at the open foundry, the “valley of death” that lies between product realization and commercialization can be overcome, and it will contribute to the establishment of business through which society can enjoy the innovation, and go further to establish new industry.[14] In packaging, the sifting and selection, and the linking of the research results or elemental technologies are done by people. The issues at the open foundries of the independent administrative bodies and universities are the training of process engineers that conduct the technological development, and the reduction of the barrier in moving personnel to the production center to which the technologies are transferred.

For the open foundry to create new users, it is important that diverse human resources gather at the foundry, and for the management to make it the center at which creative, young people will be trained. NPF holds a school for training and

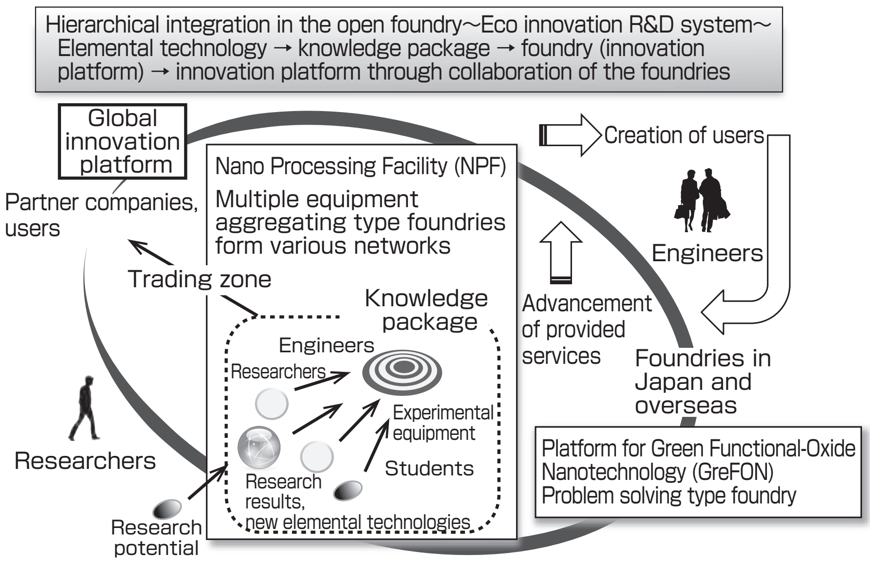

Fig. 5 Scenario to realize eco innovation

The open foundries that create knowledge packages by integrating the research results and new elemental technologies nurture their own innovation platforms. The open foundries advance the knowledge packages provided. The researchers, engineers, and users who have the advanced knowledge packages promote the collaboration of these foundries, and by integrating the innovation platforms, an even more advanced innovation platform can be built. This mechanism is the eco innovation R&D system.

provides a diverse curriculum. The school participants not only start using the foundry as new users, but also form spontaneous links with device developers that cooperate with the school and other students. There are several examples where new research topics and new users who pursue new topics were born from such linkages. This means that, by providing the users the value of practical skill improvement at the open foundry, the attractiveness of the foundry to the users increases. The increased user attraction is a profit for the foundry. Also, the increased skill is a profit for the user possibly amounting to more than the beneficiary pay. Therefore, the strengthening of the human resource training project has become an essential issue for the open foundry, as a way to resolve the dilemma described in subchapter 2.3. Recently, widening the human resource network overseas is being recognized as the issue of the open foundries in Japan. NPF has promoted information exchange with the foundries in various Asian countries since its inception,[15] and has started the energy element development support project in collaboration with CINT of the United States since FY 2010. Management for creating a global innovation platform transcending the country boundaries and the organization of the related rules are issues that need to be considered.

5 Summary – scenario for realizing eco innovation

Open foundry is a tool to construct a place where "people" and "knowledge" convene, by widely sharing the state-of-the-art "equipment." The open foundry has the mechanism to efficiently distribute the "people" and "knowledge." This is the open innovation function, and the meaning for AIST operating the open foundry. P.F. Drucker stated, "There is only one valid definition of business purpose: *to create a customer* (value). .... the business enterprise has two - and only two - basic functions: marketing and innovation."[16] Following this statement, "marketing" for the foundry is the act of offering the equipment and technical know-how necessary to deliver the product desired by the user, whereas "innovation" is the creation of new users and new support requests using the powers of research promotion and development execution of the foundry and its ability to aggregate and transmit IP and information.

Figure 5 shows the scenario for promoting eco innovation in which there are global innovation platforms which are integrated hierarchically with the foundry at the core, and the platform space expands continuously. In this paper, this hierarchical integration is named the "eco innovation R&D system," but the main players that promote this system are "people." Professor S, whom the author respects, said, "It is important for Japan to nurture a culture where the users who conduct R&D and the engineers in charge of the process technology development acknowledge (respect) each other's values. We must establish a true foundry for that purpose." The big circle in the figure joins the researchers and the engineers by equal partnership. This circle strengthens the collaboration of the foundry, and generates the overlap of the respective innovation platforms. The construction of a sturdy and healthy circle is the continuous issue for the open foundries not only at the AIST but also throughout Japan.

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Note) Professor N, whom the Author respects, calls this the "proximity effect."

References

[1] *Shuyo-koku No Nanotekunoroji Seisaku To Kenkyu Kaihatsu Kyoyo Kyoten* (Nanotechnology Policy and R&D Sharing Center of Major Countries), G-TeC Report (CRDS-FY2011-GR-01), Center for Research and Development Strategy, Japan Science and Technology Agency (2011) (in Japanese). http://www.jst.go.jp/crds/pdf/2011/GR/CRDS-FY2011-GR-01.pdf

[2] Nanotechnology Research Directions for Societal Needs in 2020, Retrospective and Outlook, (Sept. 30, 2010), http://www.wtec.org/nano2/

[3] MEXT Nanotechnology Platform (in Japanese). https://nanonet.go.jp/

[4] H. Chesbrough, W. Vanhaverbeke and J. West (eds.): *Open Innovation: Researching a New Paradigm*, Oxford University Press (2006) [PRTM ed. and T. Nagao trans.: *Opun Inobeshon: Soshiki O Koeta Nettowaku Ga Seicho O Kasokusuru*, Eiji Press (2008) (in Japanese)].

[5] T. Degawa: *Gijutsu Keiei No Kangae-kata* (Thinking for Technology Management), Kobunsha (2004) (in Japanese).

[6] T. Ueyama: *Akademikku Kyapitarizumu O Koete* (Beyond Academic Capitalism), NTT Publishing (2010) (in Japanese).

[7] G. Hardin: The tragedy of the commons, *Science*, 162 (3859), 1243-1248 (1968).

[8] T. Akimichi: *Komonzu No Chikyushi* (Global History of the Commons), Iwanami Shoten (2010) (in Japanese).

[9] Tsukuba Innovation Arena for Nanotechnology (TIA-nano) (in Japanese, English available). http://tia-nano.jp/

[10] Inobeshon Shisutemu Ni Kansuru Chosa - Dai 4 Bu Kiban Tonaru Sentan Kenkyu Shisetsu (Innovation System Survey, Part 4: Advanced Core Research Facility), NISTEP Report No. 130, National Institute of Science and Technology Policy, MEXT (2009) (in Japanese).

[11] Y. Aoshima and T. Kato: *Kyoso Senryaku Ron* (Strategic Management), Toyo Keizai (2012) (in Japanese).

[12] N. Kobayashi, M. Akamatsu, M. Okaji, S. Togashi, K. Harada and N. Yumoto: Analysis of synthetic approaches

described in papers of the journal *Synthesiology* - Towards establishing synthesiological methodology for bridging the gap between scientific research results and society (Discussion with Reviewers 5), *Synthesiology,* 5 (1), 36-52 (2012) (in Japanese) [*Synthesiology English edition*, 5 (1), 37-55 (2012)].
[13] [Example published as an academic paper] K. Hata, Don N. Futaba, K. Mizuno, T. Namai, M.Yumura and S. Iijima: Water-assisted highly efficient synthesis of impurity-free single-walled carbon nanotubes, *Science*, 306, 1362-1364 (2004).
[14] Handotai Senryaku Purojekuto – Sangyo Kyosoryoku Kyoka No Tameno Sentan Kenkyu Kaihatsu (Semiconductor Strategy Project – Advanced R&D to Strengthen Industrial Competitiveness), Final Report of FY 2011 Project, Council on Competitiveness Nippon (2012) (in Japanese). http://www.cocn.jp/common/pdf/thema41-L.pdf
[15] Asia Nano Forum. http://www.asia-anf.org/
[16] P. F. Drucker: *Management: Tasks, Responsibilities, Practices*, Harper & Row (1973) [A. Ueda, trans. & ed.: *Manejimento Essensharu Ban*, Diamond (2001) (in Japanese)].

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Discussions with Reviewers

1 Overall comment

Comment (Akira Ono, AIST)

This paper addresses the issues of open foundries to promote open innovation, and the author, who has plenty of experience in the actual management of such a facility, explains the scenario for its operation, the accomplishments, and the evaluation. The paper contains much information that should help the users and operators of foundries, and it is an excellent paper for *Synthesiology.*

2 Transmission of the knowledge package

Question & Comment (Hiroshi Akoh, Evaluation Department, AIST)

In the global innovation platform system, I think the transmission as well as the creation of the knowledge package is important. Please indicate the measures and methods for the transmission of the knowledge package.

Answer (Hiroyuki Akinaga)

The information transmission service is literally the first step in increasing the attraction for promoting open innovation. NPF categorizes the services it provides into the following eight: (1) technological consultation, (2) use of equipment, (3) technical support, (4) product creation support, (5) on-site training, (6) human resource training, (7) information transmission, and (8) networking.

The (7) information transmission service includes the publication of newsletters and textbooks and organization of various workshops, and recently we started using the ICT media such as Facebook. For example, results of a characteristic microfabrication process may be introduced in a newsletter, and we offer the knowledge package of the microfabrication process to the users who participate in NPF. On the other hand, the mechanisms for gathering the know-how for microfabrication or nano measurement/analysis, creating the archives, and sharing them among multiple users to further advance such knowledge have not been built, and we are currently working on it by trial-and-error. In reality, it is quite difficult to make clear-cut decisions, such as the research results should go to the users while the advanced technological know-how go to the foundry, or the process know-how described on the upper right of Fig. 2 should be used for supporting the research of a new set of users. I am aware these are future subjects to be studied.

3 Dilemma in operating the foundry

Question (Akira Ono)

In subchapter 2.3, you mention one of the dilemmas in operating the open foundry. Can you briefly describe any other operational dilemmas, other than the ones mentioned in this paper?

Answer (Hiroyuki Akinaga)

In subchapter 2.3, I described the dilemma of making use of idle time and the beneficiary pay, so here, I shall introduce the dilemma of fee setting and the beneficiary pay system.

When a sharing system of the state-of-the-art equipment is organized and made available, the equipment that is on the leading edge and has an easy-to-use sharing system will be used and reserved more, and as a result, many users can share the cost of operating that equipment. Here, when the actual cost necessary for the operation is allotted as the maximum cost of the equipment that can be paid by the beneficiaries, the following dilemma occurs. If the actual cost is set as the maximum, the charge for that particular equipment decreases through cost sharing. Because low charge is an attraction that brings in more users, as in the dilemma of idle time and beneficiary pay, the equipment aging is accelerated due to the cost reduction, and the "tragedy of the commons" will soon occur. From the perspective of managing the facility, I think it is better to set the charge higher for equipment that is used more frequently. For example, high charge setting has the effect of improving the congestion degree of machine use. Also, the excess charge collected over the actual cost can be allotted to additional installment of similar equipment or for the replacement of aged equipment, and as a result, this will further benefit the users.

On the other hand, someone with an excellent idea does not necessarily have sufficient R&D budget, and the open foundry must play the role of reducing the financial burden to such a person and support the startup of R&D. The organization of a system that promotes trial use by users is another future issue for the open foundry.

4 Updating the state-of-the-art equipment

Question (Hiroshi Akoh)

In subchapter 2.3 "Dilemma of managing an open foundry," I understand very well the importance of efficient use and the deceleration of the aging cycle. Can you tell us the policy for updating old equipment or introducing new state-of-the-art equipment?

Answer (Hiroyuki Akinaga)

When the NPF was first established, we prioritized the construction of integrated processes such as for material analysis, thin film growth, lithography, and device evaluation. Recently, since NPF is a network type foundry and is complementary to the collaborating foundry group, new equipment is introduced with the policy of advancing technology in the nanoelectronics or material science fields that are our strengths. For example, in the Nanotechnology Platform Project in which NPF is participating, other institutions have several devices for electron beam lithography and electron beam mask lithography, so NPF introduced a lithography device with excellent turnaround time. Moreover, priority is given on introducing state-of-the-art equipment for device fabrication process and evaluation.

5 Collaboration of foundries across the institutions

Question & Comment (Akira Ono)

In chapter 5 and Fig. 5, you indicate the scenario for hierarchically integrating foundries across different institutions to nurture global innovation platforms. I hope that the scenario is developed further in the future. Is such attempt taking place in the field of nanotechnology, and if so, how is it being done?

Answer (Hiroyuki Akinaga)

Other than the Nanotechnology Platform Project of Japan and NNIN of the United States described in subchapter 2.1, there are foundry networks in Taiwan, USA, the Netherlands, Australia, and others. With the United States, we have networks for microfabrication, measurement, and simulation, and there are hierarchical collaboration for microfabrication, microstructure analysis, and molecular/substance synthesis in the Nanotechnology Platform Project. In fact, while managerial issues remain in handling the intellectual property and the contracts for conducting research, the users who conduct R&D at these "network of networks" can utilize the foundries that belong to multiple organizations according to their objective and research phases, and have been successful in accelerating their R&D.

At NPF, increasing number of users are utilizing the foundries of multiple organizations that participate in the Nanotechnology Platform Project, such as the National Institute for Materials Science, the University of Tokyo, Tokyo Institute of Technology, and Kyoto University. Recently, NPF has started to utilize ICT technology to promote foundry collaboration with the Asian countries,[15] and we wish to become an open foundry with international attraction.

6 Comparison of the open foundry with a library

Question & Comment (Akira Ono)

I do not think it is easy to continuously and smoothly operate a research foundry at universities and public research institutions. In the past, analytical instrument centers were established as open foundries by universities, but it is generally thought they never took hold.

On the other hand, a library is an open facility for sharing books and resource materials, and its management at the universities and research institutions has been firmly established. Compared to an open foundry of equipment, what are the reasons that the library is so successful? Is it simply tradition and length of experience that make the difference?

Answer (Hiroyuki Akinaga)

The management of an open foundry is often compared to the management of a general hospital, but I think it is useful to compare it with a library.

In the operation of a library, the Five Laws of Library Science (Reference S1, S2) are widely known: "(1) books are for use, (2) every reader his/her book, (3) every book its reader, (4) save the time of the reader, and (5) the library is a growing organism." By replacing the "book" with "equipment or knowledge package including the know-how," "reader" with "user," and "library" with "foundry," for the Five Laws, I think we have the managerial policy of an open foundry as an innovation platform. The Five Laws were written in 1931, and for example, (2) indicates the social significance of the library and the issues of financing to achieve the objective, and (4) indicates a wide range of issues, from a library system to improve the readers' service to shelving and categorization of books. As you indicate, the library has tradition and accumulation of experiences for its management. Recently, there are reports of new attempts by the library to contribute to the creation of new knowledge by offering open access (Reference S3).

Studies of open foundry management is yet to be done systematically and academically. However, in the past 10 years, I think the importance of foundries at universities and research institutions is being strongly recognized. As shown in Fig. 5, a foundry promotes diverse R&D, and can be a place to return the results to society. Therefore, it must be able to play the due role as a bridge between research and society. The author believes that foundries will play a major part in the social acceptance of R&D results in the next 10 years,[2] and I hope this paper will be read as precursory advice by readers from wide-ranging fields.

[S1] M. Kon: *Toshokan-gaku Kiso Shiryo Dai 10 Pan* (Basic Material for Library Science, 10th Edition), Jusonbo (2011) (in Japanese).

[S2] S. Takeuchi: *Toshokan No Ayumu Michi* (Road Trodden by Libraries), Japan Library Association (2011) (in Japanese).

[S3] R. Monastersky: The library reboot, *Nature*, 495, 430-432 (2013).

7 Scenario for foundry management and its time schedule

Comment (Akira Ono)

The construction of the nanotechnology open foundries at AIST was started in the beginning of the 2000s, and I think there was a vision (or scenario) of what kind of foundries they should be at the start. If you compare the scenarios of the 2000s and 2010s, I think the readers will better understand the development of the open foundry at AIST in these 10 years.

Question & Comment (Hiroshi Akoh)

In chapter 1, the organization and advancement of the foundry are positioned as the issues toward 2020. I think the scenario described here sets this timeframe as a goal. Therefore, I think the understanding will deepen, if you indicate the time schedule for the realization of the scenario. Also, by describing the positioning of the goal year 2020, I think the dynamics of the scenario for strategic management will become clearer.

Answer (Hiroyuki Akinaga)

The scenario that NPF wrote initially is described in subchapter 3.2, and the time schedule in subchapter 4.2. The author stated in Reference [2] that the evolution process of the foundry will be to become: a "user facility and network of user facilities" in 2005, "problem-solving user facilities, and networking" in 2010, and a "user facility as a center of science and technology formation" in 2015. I think the foundry in 2020 should be a "user facility in society, as a demonstrative test area and for outreach activities."

8 Aim of the corporate utilization of the open foundry

Question & Comment (Akira Ono)

As you describe in subchapter 4.2, I think it will be wonderful if the private companies engage in the whole process from target setting to packaging "at the open foundry." However, due to various reasons such as corporate secrets, isn't it normal that the private companies position the open foundry as one of the tools for the development and demonstration of elemental and core technologies? I imagine that although open innovation is important, "target setting" and "packaging" are done within the respective companies. Although I think the situations at SCR and NPF are different, even if the open foundry is merely one of the tools, isn't the use of the "open foundry" highly valuable for the companies?

Answer (Hiroyuki Akinaga)

This is an important discussion point concerning the role of the open foundry in industry. As you indicate, there are many cases where private company users conduct only part of the practical R&D process, particularly at the networking type or knowledge accumulating/integrating type foundry described in subchapter 2.1. This is the same at NPF. For example, they include elemental technology development when introducing new materials into a manufacturing process, or prototyping of a device and its property evaluation. In introducing new materials or technology, there are many cases where the results as planned cannot be obtained, and the use of the foundry can be seen as a risk avoidance activity, and is an example of "handling uncertainly" described in subchapter 2.2 and subchapter 3.2.

On the other hand, a bottleneck may become apparent in an R&D process, and if a new target must be set as a result, NPF may provide support from the phase of target setting, through the clarification of technological issues, the discovery of the cause of failure, and the swift provision of knowledge and technology needed to resolve them (Reference S4). In the process of new R&D, whether the responsibility for packaging the elemental technology falls on the private company or NPF depends on the case. However, it is not rare that NPF handles not only the process development, but also the obtainment of intellectual property (IP) rights through patent application, the development for field testing device, and the packaging of knowledge, in cases where NPF is closely involved in the R&D from the initial target setting. In such cases, as you have alluded, the issue will be the agreement on establishing a boundary between the background IP originally owned by the company and the foreground IP developed at NPF. Moreover, utilizing the foreground IP as the background IP in the innovative platform with NPF at the core is essential in realizing the eco innovation R&D system. We hope to build up successful cases one by one.

As a supplementary explanation, in the survey for NPF in Reference S4, there were many respondents who said, "NPF was useful for qualitative improvement or improvement of skills of the researchers." Not just for R&D promotion, but also from the perspective of employee training, the value of the "open foundry" for the private companies is increasing. In fact, there are companies that use the training sessions at NPF as part of their employee training program.

[S4] Monbu Kagaku Sho Sentan Kenkyu Shisetsu Kyoyo Innovation Soshutsu Jigyo "Nanotechnology Network" (MEXT Project on Common-Use Research Facilities for Innovation Creation "Nanotechnology Network"), Research Topic Follow-up Survey Report (2012) (in Japanese).

9 Merit of using the NPF for the companies and research groups

Question & Comment (Akira Ono)

Ten years have passed since the establishment of NPF at AIST. It has received continuous support of MEXT, and I am glad that our sponsor considers it a success. On the other hand, I think the degree of success is determined by the evaluation of the companies and research groups that participated in NPF.

Therefore, I would like to know the evaluation of the users about NPF, such as what merits were gained by the companies and research groups that were involved in NPF. However, I'm afraid the "quantitative and objective" evaluation like a statistical data may not necessarily be available. Can you, the author, who have interacted with the users on a daily basis and have actually managed NPF, introduce user evaluation for NPF even if it may be the "qualitative and subjective" version of the case studies?

Answer (Hiroyuki Akinaga)

NPF has promoted various human resource training projects such as the schools for microfabrication, nano measurement, and nano analysis. Questionnaire surveys were done after the schools to obtain responses from the students, to plan the curriculum for the school that would be held the following year. Recently, in the free response section of the questionnaire, I see more responses like "I participated in the school because my boss introduced me to it" or "I want to recommend it to my subordinates." As I answered in Discussion 8, I think there are many cases where the companies and research groups think, "It was useful for the qualitative improvement or improvement of skills of the researchers."

Also, NPF regularly conducts user satisfaction surveys. For example, in the questionnaire done in February 2007 (105 valid responses), to the question "Was your initial objective obtained through our support?" the percentage of answers "results surpassing expectations were obtained," "obtained," and "almost obtained" was 73 %. To the question "Were the results obtained through our support useful?" the percentage of answers "very useful" and "useful" was 92 %. We received an evaluation that "the user satisfaction is high even if a result different from what one expected was obtained," and from that perspective, the author highly praises the will and skill of the engineers (technical staff) who work at the sites of NPF.

Moreover, in the questionnaire survey of the NPF users conducted by an organization of the MEXT projects in June to July 2013, there were the following messages: "It was very encouraging that you gave me beneficial findings in addition to very detailed and careful explanation in the technological support" from a university user; and "You went as far as innovative technological development in the technological support…" from a corporate user. On the other hand, an independent administrative body institution user indicated, "Before actually using the facility, there are several steps of procedures on the web system and it is difficult to get through. However, the explanations of the respondent and personnel in charge were very easy to understand, and I am grateful." We are improving the NPF system* by revising the procedures for using the facilities from the user's viewpoint, to realize a readily accessible facility.

*NPF system: https://nanoworld.jp/npf/
NPF system is a support system to smoothly manage NPF. It was developed to realize "(4) save the time of the reader (user)" in the Five Laws of Library Science, described in the answer for Discussion 6. From the user side, the electronic application system enables requesting support, reserving equipment, confirming charges, and others. From the NPF side, the system enables the management of homepage display, various databases, progress of support, charge account, and others.