Science & Technology Forecasting Aimed at Meeting Societal Challenges

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Introduction

Producing and utilizing science and technology forecasts and technological roadmaps are of great importance from a long-term perspective, whether it is for developing plans for new businesses or for laying out R&D strategies for developing new products.

But science and technology forecasting and technological roadmapping must also adapt to the shift of technological and social demands away from the single-minded focus of 20th century technology — faster, stronger, bigger, smaller and so on — to the growing multiplicity of our times. Likewise, there has been a major methodological shift away from forecasting, which looks at the future from the here and now, towards backcasting, which works back from ideal outcomes to be achieved and societal challenges that must be resolved.

Moreover, as a matter of R&D strategy, forecasting results and roadmaps could be proactively disclosed to expand markets in an inclusive manner or, alternatively, they could be maintained in strict secrecy in order to maintain competitive edge. It is necessary to fully consider which method is desirable, taking into consideration such factors as the nature of that particular industry.

Here, I shall focus on how science and technology forecasting has come to focus on meeting societal challenges and also how it relates to the enhancement of industrial competitivity by securing competitive advantages.

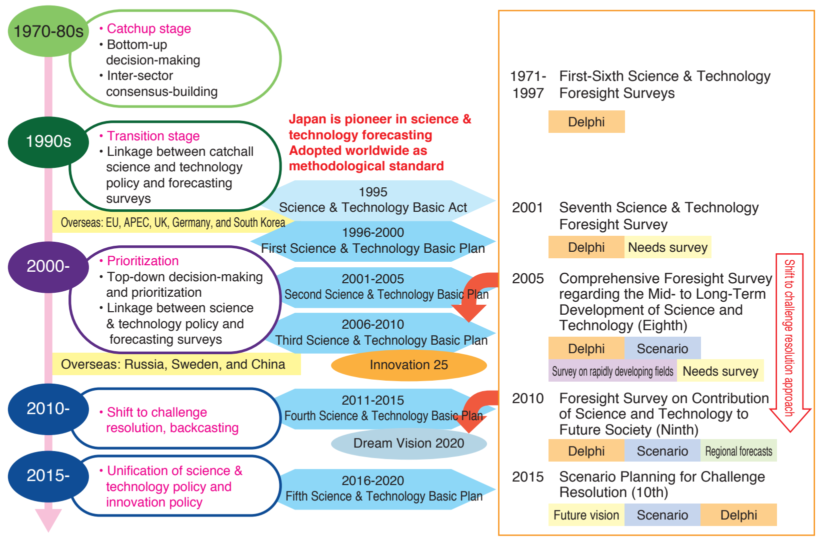
Technological Forecasts & Roadmaps from the Government

The Japanese government has a long history of science and technology forecasting and technological roadmapping that goes back to the 1960 report by the Science and Technology Agency entitled “Steps towards the 21st Century”. The agency later began conducting technological forecasting surveys in earnest in 1971, with a large-scale survey based on a questionnaire directed at 2,000-4,000 experts conducted roughly every five years (by the Ministry of Education, Culture, Sports, Science and Technology [MEXT] since FY2001). The survey for the FY2015 report (conducted in FY2014) is the 10th in the series. The main purpose of the survey is to provide information regarding the generation and prioritization of science and technology R&D that contributes to the formulation of the Science and Technology Basic Plan and the strategies of the respective ministries and agencies.

The Strategic Technology Roadmap issued annually since FY2005 by the Ministry of Economy, Trade and Industry (METI) is a technological roadmap that is more closely associated with industries. The main elements of this roadmap, which responds to the specific needs of industries, are a technological map that provides an overview of important technologies, a technological roadmap with detailed year-by-year plans, and a scenario for the social assimilation of the technologies. However, the roadmap exercise has been limited in sector coverage since 2011 due to the demands of the response to the Great East Japan Earthquake that occurred that year. We hope that it will be resumed in full in the near future.

CHART 1

Changes in the Science & Technology Foresight Survey



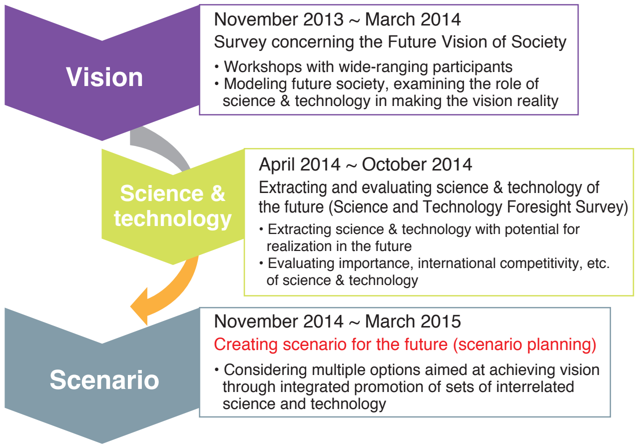
Source: Tenth Science & Technology Foresight Survey (Preliminary Overall Summary), November 2014, *National Institute of Science & Technology Policy (NISTEP), Ministry of Education, Culture, Sports, Science & Technology (MEXT)*

Transition towards Meeting Societal Challenges

Chart 1 shows how science and technology forecasting has changed over the years, from the First Science and Technology Foresight Survey in

CHART 2

"Vision of the Future" to "Technology Forecast" to "Scenario Planning": a conceptual diagram



Source: Tenth Science & Technology Foresight Survey (Preliminary Overall Summary), November 2014, *NISTEP, MEXT*

1971 to the Sixth Survey in 1997, the Delphi method, in which experts go through two rounds of questionnaires on technological challenges as to the timing of the realization of the technologies and their respective significance. The purpose of having two rounds is to achieve convergence in the survey results and develop a consensus by providing a summary of the results of the first round to the same experts and conducting the second round in the light of that resultant understanding.

Change becomes apparent in the mid-1990s. Most conspicuous in marketing, it was becoming increasingly difficult to discern the needs and wants of society at large.

When technology had yet to fully satisfy people's needs, for example in the period up to the 1970s when the "Three Sacred Treasures" — refrigerator, television set, and washing machine — had not reached all households, everything that manufacturers produced could be sold at once. In the 1980s, one-to-a-household products by and large reached saturation point, and the individual became the target consumer. But marketers could still figure out what people wanted through segmented surveys (age, gender, occupation, region, etc.).

However, in the 1990s, individual wants were also more or less satisfied, making it impossible to plan new products without giving full consideration to what would be needed in the future.

This trend rapidly became apparent in the field of technology forecasting as well, as technology development became increasingly diversified. This led to a movement seeking to identify technologies for development by first grasping what future needs would be. Thus, a needs survey was incorporated into the Seventh Technology Foresight Survey in 2001. However, this led to a new problem. The British government's science and technology forecast conducted around the same time under its Foresight Programme saw future needs diverge with the result that it could not be fully grasped which ones were of importance to the future. The same thing happened to the Japanese survey.

Thus, it became necessary to transition to backcasting, where an image of a desirable future is first posited, and then the societal and technological challenges that must be resolved along the way are discussed in order to determine the technologies that should be developed. Scenario planning was introduced in the Eighth Technology Foresight Survey in 2005 in order to draw out the images of desirable and/or possible futures. In the Ninth Technology Foresight Survey in 2010, a new attempt was made to use technological challenges in the questionnaires as scenarios for resolving societal challenges.

The ongoing 10th Technology Foresight Survey has been designed on the basis of this experience. The key lies in resolving the dilemma between an emphasis on technological seeds, which could obscure contributions to the resolution of societal challenges, and an emphasis on the resolution of societal challenges, which could leave the survey short of cutting edge science and technology challenges.

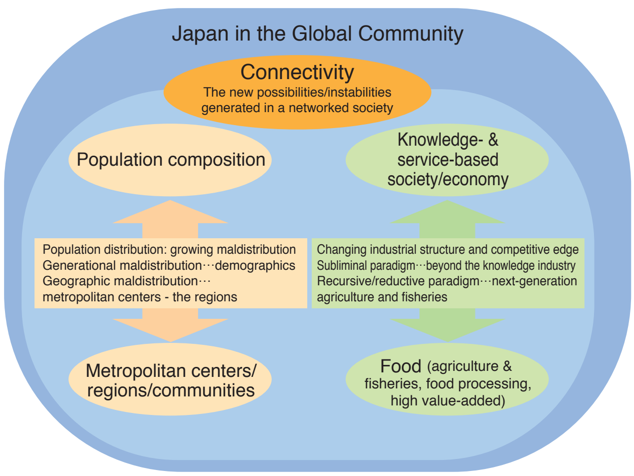
Constructing a Vision of the Future as the Starting Point

The 10th Technology Foresight Survey adopts a three-stage approach in which the vision of the future is fully discussed in order to draw out societal challenges, reveal through the technology forecast survey what kind of technology portfolios should be secured in order to resolve those challenges, and finally conduct scenario planning on how the technologies should be assimilated into society *(Chart 2)*.

During the deliberations on the vision of the future in particular, the framework for the survey was constructed by drawing out the social and economic macro-trends that were highly likely to occur. The macro-trend that will occur with certainty is demographic change. The Japanese population has entered a declining stage, making it necessary to deal with the challenges that come with it, such as an aging population combined with the diminishing number of children, a declining working population, and increasing healthcare costs. With regard to the industrial structure, the rise of tertiary industries is

CHART 3

Macro-structure of the Vision of the Future



Source: Tenth Science & Technology Foresight Survey (Preliminary Overall Summary), December 16, 2014, *NISTEP, MEXT*

TABLE 1
Moves to be made in anticipation of societal changes

Challenges to be met (moves to be made)	Contents
Building barrier-free relationships	Physical functions/constitution/physical and mental ailments, language/ culture, social conditions
Adapting to the digital society, securing real-world tactility	Achieving complexity/multiplicity/creativity, Shaping digital communication (dealing with the revolutionary/radical/extreme), interface technology (tactility, etc.)
Monozukuri "Manufacturing" Platform	Extensibility (adding functions, dealing with special orders); Maintenance solutions; Open sourcing/modularization; high added-value; Convergence with services PSS
Pursuing cost-effectiveness in premium market segments	Latest technology, enhancing efficiency through integration
Making matching between needs and solutions	visible, utilizing big data, matching information, collecting information from clients' perspectives
Transition to a knowledge- and service-based economy	Services using information derived from product measurement, Services anchored in things, elimination of entrance barriers, the sensibility factor
Rediscovering the allure	Fundamental technologies in Japan, traditional crafts, *omotenashi*
Expanding human functions	Maintaining and enhancing health, enhancing abilities, brain sensing
Enhancing human lifetime value	Increasing mobility, visualizing/demystifying skills/potential, transforming businesses into platforms; lifelong education; early capability assessment
Reinventing the city	Resilient/robust society, megacity maintenance/disaster prevention; concentration; sharing/decentralization/autonomy, urban special zones
Developing countries	WEHAB + P (water, energy, health, agriculture, biodiversity, eliminating poverty), reverse innovation
Securing food resources	Food security, selective breeding, improving farming methods; reducing food loss
Building capacity for discovering societal challenges	NPOs and NGOs

Source: Tenth Science & Technology Foresight Survey (Preliminary Overall Summary), December 16*, 2014, NISTEP, MEXT*

TABLE 2
Categories & subcategories of science & technology & number of challenges

Categories (abbreviations in parentheses)	Subcategories	Number of challenges
ICT-analytics (ICT)	Artificial intelligence, image and language processing, digital media/ databases, hardware architecture, interaction, networks, software, HPC, theory, cybersecurity, big data/CPS/IoT, ICT and society	114
Health/healthcare/life sciences (health and healthcare)	Pharmaceuticals, medical devices and technology, regenerative medicine, common diseases, catastrophic illness and rare diseases, neurological and mental disorders, emerging and reemerging infectious diseases, health and healthcare information/epidemiology, platform technologies	171
Agriculture, forestry and fisheries/ food/biotechnology (agriculture, forestry and fisheries)	Agriculture: High production, developing crops, preventing and eliminating disease, utilizing biomass, environmental protection Food: High production, distribution and processing, food safety, food functionality Fisheries: Resource preservation, breeding and production, environmental protection Forestry: High production, utilizing biomass Common: Information services, others	132
Space/ocean/earth/scientific foundations (science platform)	Space, ocean, earth, earth observation/forecasting, accelerator/particles, atomic nucleus, synchrotron radiation (applied irradiation), neutrons/muons/charged particles/etc. (applied irradiation), computational science/simulation, mathematical sciences/big data, measurement platform	136
Environment/resources/energy (environment and energy)	Energy production, energy consumption, energy distribution/conversion/storage/transportation, resources, reuse/recycle, water, global warming, environmental protection, environmental analysis/forecasting, environmental creation, risk management	93
Materials/devices/processes (materials)	Creating new substances/materials/functions, advanced manufacturing, measurement/analysis methods for cutting-edge materials/devices, applied devices/systems (sectors: ICT/nanotechnology, environment /energy, infrastructure)	92
Social infrastructure (social infrastructure)	National land development/conservation, urban/architecture/environment, infrastructure maintenance and repair, transportation and distribution infrastructure, vehicles/railways/ships/aircraft, disaster prevention and mitigation information	93
Transition to a knowledge and service-based economy (services)	Business management/public policy, knowledge management, product service systems (PSS), societal design/simulation, services sensing, service design, service robots, service theory, analytics, basic research in the humanities	101

Source: Tenth Science & Technology Foresight Survey (Preliminary Overall Summary), November 2014*, NISTEP, MEXT*

inevitable, as the heuristic Petty-Clark's law indicates, and it has become known that there is an urgent need to generate added value from services, orient manufacturing towards services, and expand the scope of Product Service Systems, etc.

In this context, I would like readers to look at *Chart 3*. It shows the macroscopic interrelations among the three factors in our vision, namely demographic change, a knowledge and service-oriented economic society, and lastly networks and information and communications technology (ICT) connecting all the world. This is a key to understanding our vision.

Table 1 lists the moves to be made in anticipation of the societal changes that have been extracted from the vision of the future.

Technology Forecast as the Starting Point

As stated in the previous section, the societal challenges become clear when the vision of the future is used as the starting point, but their connection to R&D challenges does not. Here, it becomes necessary to turn resolutely to the scientific and technological seeds in order to build a technology portfolio of the future.

To this end, in the technology forecast, science and technology was classified on a disciplinary basis, from which items where future R&D results could be expected were extracted. However, the disciplines to be used did not simply follow conventional technological categories, but instead were determined with an emphasis on taking into consideration technology fusion and cross-sector relationships between related technology fields.

For example, electronics, communications, and information are established independent disciplines, but the increasing prevalence of integrated systems and networks have brought them inextricably together as ICT. Moreover, ICT as hardware and big data and other forms of information, and analytical tools as software have likewise become inseparable. Thus, they were posited as the single sector ICT-analytics.

Since services are not only growing as a sector but also connecting with manufacturing to form Product Service Systems (PSS), it was decided that these would be considered under the single concept of the "transition to a knowledge- and service-based society/ economy". Since environment, resources, and energy are not independent concepts and many tradeoffs are generated between them, it was decided that they would be considered together cross-sectorally. In this way, the ongoing technology forecast assorts technologies into eight categories, which are shown in *Table 2*. Around 100 scientific and technological challenges (R&D subjects) were established for each of the eight categories for a total of 932 challenges.

The experts were asked regarding each of these scientific and technological challenges to determine year of realization and year of social assimilation; give a four-level assessment of its R&D characteristics for importance, uncertainty, discontinuity, ethical value, and international competitivity; and choose for future emphasis one policy area out of human resources strategy, resource allocation,

TABLE 3

Examples of the 100 important challenges per sector

Area	Challenges
ICT	Developing data utilization techniques with theoretically guaranteed preservation of privacy
ICT	Technology to develop software without security holes exploitable through remote attacks
ICT	Technology that increases coefficient of electricity performance 100-fold in very large-scale 1 million node-plus supercomputers and big-data IDC systems
ICT	Easy-to-use, inexpensive personal authentication systems that can be used safely when accessing large numbers of websites over long periods of time
ICT	Systems that provide optimal nursing and healthcare at low cost through real-time monitoring of the condition of patients
Health and healthcare	Inexpensive and easy-to-install dementia patient assistance systems
Health and healthcare	Medical technology to regenerate auditory and visual functions
Health and healthcare	Preventive medicine to suppress carcinogenesis in pre-carcinomatous states
Agriculture, forestry and fisheries	Crops expected to produce harvests in deserts and other arid regions and other environments unsuitable for agriculture
Agriculture, forestry and fisheries	Long-term fluctuation forecasting technology for sardines, tuna and other major fishery resources under fluctuating environmental and harvesting conditions, as well as technology for proper management of fishery resources based on the forecasting technology
Agriculture, forestry and fisheries	Technology to remove radioactive substances in order to revive fishing in coastal areas
Science platform	Assessment of degree of urgency regarding all active volcanos in order to identify volcanos that are likely to erupt next
Science platform	Technology to observe local structure and electronic state — information essential to the elucidation of the expression mechanism and control of the functions of functional materials—in nanometer and femtometer scales
Science platform	Technology using high-resolution simulation and data assimilation to forecast within hours localized rainstorms, tornados, hailstorms, snow, etc. at spatial resolutions of 100 m or less
Environmental and energy technology	Mineral extraction and mining technology needed for extracting ocean mineral resources
Environmental and energy technology	Technology to forecast the impact of climate change on food production
Environmental and energy technology	Contaminated water purification and reuse technology that is economically viable for general use in developing countries
Materials	Automotive battery with 500 km range at current size and weight
Materials	Integrated circuit technology that enables single chips to reach the performance levels of existing supercomputers by enhancing information processing ability without increasing electricity consumption per unit area
Materials	Simulation technology that makes it possible to predict structures that have the desired functions and physical properties instead of predicting functions and physical properties for given structures
Social infrastructure	Low-emission and energy-efficient aircraft that achieves the reduction of noise during takeoff and landing, emission gas during flight and frictional resistance on the body and the improvement of the combustion efficiency of the engine
Social infrastructure	Establishment of decommissioning technology and radioactive waste disposal technology for 100 GW+ per unit nuclear reactors
Services	Robotic inspection technology for buildings and infrastructure comes into general use where human inspection is expensive or dangerous

Source: Tenth Science & Technology Foresight Survey (Preliminary Overall Summary), November 2014, *NISTEP, MEXT*

domestic and international cooperation, and enhancing the R&D environment.

I urge you to look at the ranking list for each field as well as the preliminary results of the matrix analysis, which have been published on the NISTEP website (http://www.nistep.go.jp/archives/18742).

Some prominent examples are given in *Table 3*.

Chart 4 shows the future directions that technology is likely to take. The ongoing dramatic development of ICT is generating new industries using big data analysis, while the rapid progress of data science is making things possible in the basic sciences that had been considered impossible. The rapid progress in computing in particular is reaching the stage where forecasting and designing becomes possible by analyzing massive volumes of data without fully understanding the underlying principles. For example, forecasting earthquakes and predicting volcanic eruptions had been conducted by constructing analytical models using very large numbers of parameters. However, many years passed without generating viable models, leading to the conclusion that forecasts and predictions were impossible. However, today it is becoming possible to infer that earthquakes and eruptions occur when such and such patterns are observed based on analyses using massive historical data even though the actual mechanisms have not been fully analyzed. And it is the nature of these inferences that their accuracy will improve over time as more data on ongoing phenomena are accumulated.

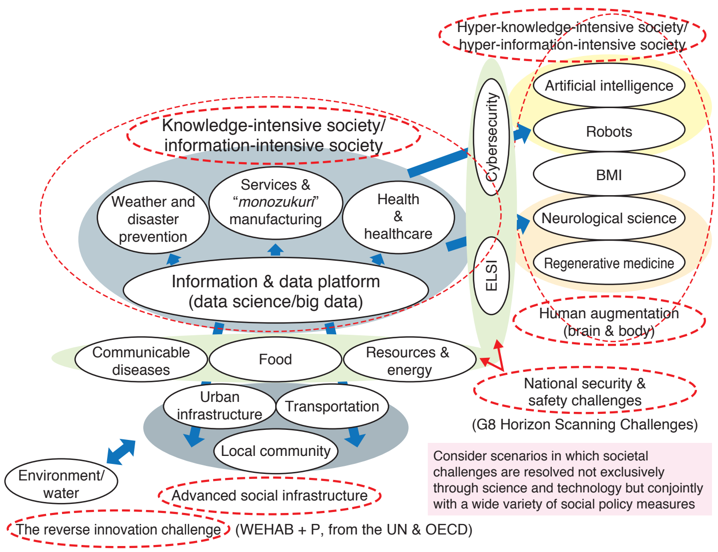
These examples are increasing not only in meteorology and disaster prevention, but also in health and healthcare, and services and manufacturing.

The next stage in the evolution of big data will be a world in which artifacts such as artificial intelligence and robots do things that are far beyond the capabilities of humankind, a world in which dramatic improvements are made in neuroscience and regenerative medicine. These future worlds are coming to be known in recent years as "the singularity" that people see as producing rapid social changes.

How should all this be broken down into R&D in the here-and-now? What industries should be created? They are the subject of the scenario that is currently being developed. The outcome of the deliberations will be available at the beginning of FY 2015. We look forward to it. JS

CHART 4

Orientation of scenario for resolving societal challenges



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