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R&D Trends for High-Energy Automobile Capacitors to Hasten CO_2 Reductions

U.S. Science and Technology Policy under Tight Budgets: Report on the 2012 AAAS Forum on Science and Technology Policy

United States Government Efforts concerning Big Data

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Executive Summary

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Society is demanding storage systems that maintain higher and higher power output and energy capacity as policies encourage cuts in CO_2 emissions and greater energy conservation. Energy storage systems are rechargeable batteries such as lithium-ion batteries (LIBs) that undergo an electrochemical reaction when they store and release electrical energy, and capacitors that primarily obtain electrical energy from physical absorption and desorption of ions. Capacitors have mainly been electric double layer capacitors (EDLCs).

Capacitors are still not used much as primary power supplies for plug-in hybrid vehicles, electric vehicles and the like, which are the most demanding environments in which they are used. While capacitors enjoy advantages over rechargeable batteries such as high power density and rapid charging/discharging that allow them to respond well to load fluctuations, their long shelf-life allowing many charge/discharge cycles, good safety and high reliability, but their disadvantage of having lower energy density compared to rechargeable batteries is a major weak point. Accordingly, most research and development on capacitors is attempting to imbue them with high energy capacity. The approaches involved can be broadly categorized as giving electrode materials high capacitance and making cells with high operating voltage. The candidate receiving the most attention for the time being is a lithium-ion capacitor (LIC) with a cell structure: a hybrid capacitor employing a set of electrodes including an LIB as the anode. LICs have the same power density and charge/discharge cycle shelf-life as conventional EDLCs, along with having small self-discharge, being very safe and having excellent performance under high temperatures.

Furthermore, a fast way to raise capacitor energy density to the level of rechargeable batteries would be R&D to discover charge storage mechanisms by, for example, analyzing the structure of cells' constituent materials as well as electrochemical analysis and assessments based on compositional analysis. If a capacitor could be created with the same energy density or more as an LIB while maintaining the advantages of a regular capacitor, then it could be applied to primary power supplies or regenerative braking in automobiles, with the possibility of further applications in a wide range of storage systems for various other types of industrial machinery. We could expect the result to be a drastic reduction in CO_2 emissions.

(Original Japanese version: published in July/August 2012)

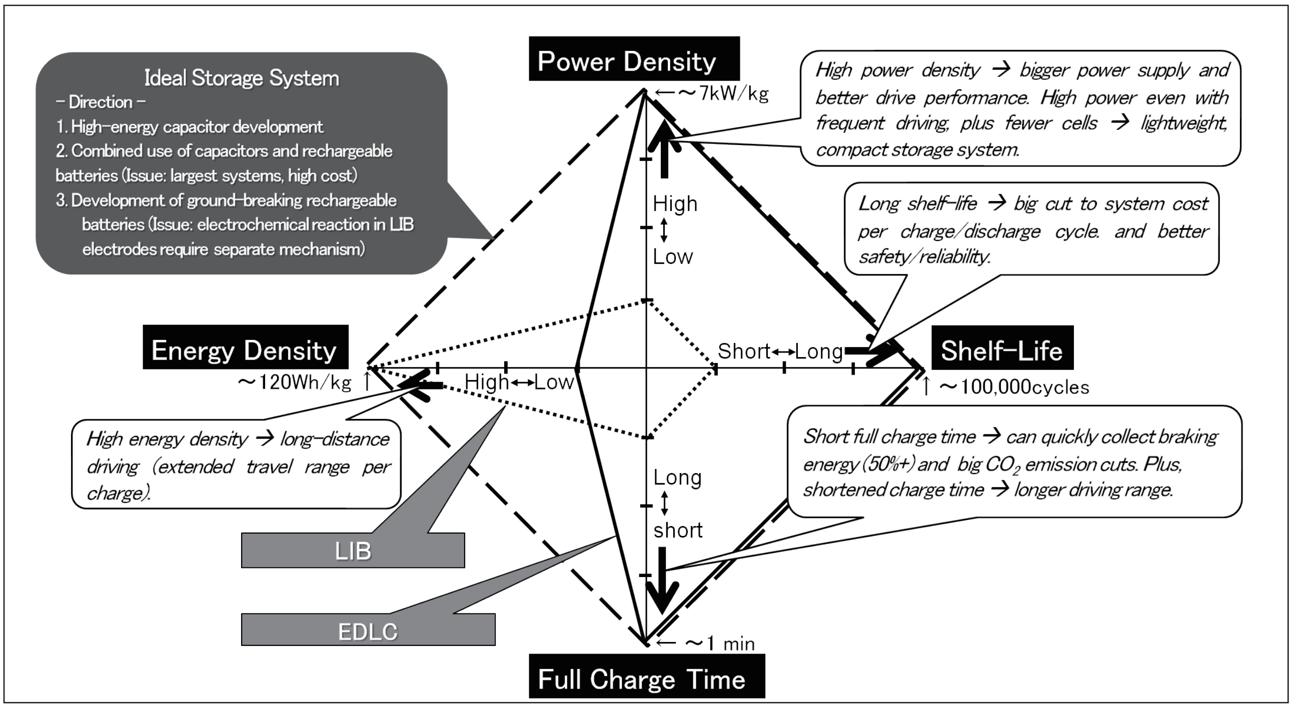

Figure : Comparison of EDLC and LIB Storage Performance--Direction of Ideal Automobile Storage System

Compiled by the Science and Technology Foresight Center

2 U.S. Science and Technology Policy under Tight Budgets: Report on the 2012 AAAS Forum on Science and Technology Policy

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The American Association for the Advancement of Science (AAAS) convened the AAAS Forum on Science and Technology Policy over two days on April 26-27, 2012 in Washington, D.C. The AAAS holds this annual forum every April or May. The forum, a gathering of the country's science and technology policy insiders, was first held in 1976 as the AAAS R&D Colloquium on Science and Technology Policy. The most recent meeting was the 37th. In addition to the Obama administration's policies (including the president's budget proposal), the forum covered topics such as higher education funding and training for skilled workers, the international standing of American science and technology, and economic growth and job creation. There were over 400 participants from universities, the federal government, non-profit organizations, private companies, overseas organizations and other institutions.

Overall, the fiscal 2013 budget proposal from the president is an austere one due, among other things, to the Budget Control Act that was passed last year. However, a slight expansion of science and technology-related budgets within the proposal showed the participants that the Obama administration places importance on science and technology. The participants also deepened their understanding on initiatives that the administration is promoting.

In addition to major shifts in financial assistance from the federal government, institutes of higher education are facing additional administrative difficulties due to cuts in assistance from state governments, and their outlook is not necessarily bright. However, university-affiliated speakers reported on future-oriented efforts under these circumstances, such as building new collaborative relationships with industry and government. There was also a widespread understanding of the importance of teaching in undergraduate education, especially at research universities.

Participants were also interested in the United States' international standing in science and technology as the BRIC countries have been experiencing rapid economic growth. Speakers shared their knowledge to promote understanding of science and technology in terms of economics, as well as labor, finance, public administration, the environment, energy and other perspectives.

Another topic of interest to the participants was the effect science and technology has on the economy and jobs. While many speakers expect science and technology to play a role in spurring economic growth, some pointed out that technological development does not necessarily benefit all people in terms of jobs. The result was that participants thought deeply as they reexamined their ideas about science and technology's relationship with society.

The forum took up diverse topics and individuals expressed various opinions. Even so, one could say that to many of the participants, this forum was an opportunity for them to inquire into what they should do to deal with the common problem of conducting scientific and technological research under tight budgets.

(Original Japanese version: published in July/August 2012)

3 United States Government Efforts toward Big Data Research and Development

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Research and development revolving around "big data" is currently making huge strides in the West. The term does not quite have an exact definition, but is rather a general way of referring to large quantities of digital data. Some specific examples are: online info that has experienced enormous growth due to the spread of social networking services (SNS) and the like; large amounts of photos and videos stored on the internet; information from "things" which is information detected by sensors and sent by communication devices; massive amounts of numerical data generated by supercomputers and so forth. A recent trend is attempts at creating new value by extracting significant information from a vast amount of digital data that has gone unused until now.

In March 2012, the United States government announced an R&D initiative to utilize big data. Six government agencies are investing over US$200 million to try and improve technologies for handling vast amounts of digital data. They see big data as science and technology that may contribute to the creation of a new paradigm and will have a very major impact in many realms, as the internet did. Noteworthy aspects of the U.S. government's focus are subjects such as the "Focus on Visualization Technology," the "Relationship with Cloud Computing," "Considerations to Human Resource Development," "Active Participation by Industry and Academia" and "Encouraging Data Sharing." We can also see that the U.S. is giving thought to policies such as those encouraging the provision of facilities and computing power conducive to collaborative work. Since the results produced by the initiative's R&D may become widely used and penetrate to society in a few years or decades, and lead to major innovations, future developments will be worthy of our attention.

Comprehensive solutions to numerous problems are needed for value creation from big data. In particular, there is an intimate relationship between analysis and visualization, and it is important to visualize and extract knowledge, then link that to action that creates value. Considering the growth of R&D into big data around the world and the difficulty of the challenges involved, global collaboration will be vital for future R&D.

(Original Japanese version: published in September/October 2012)

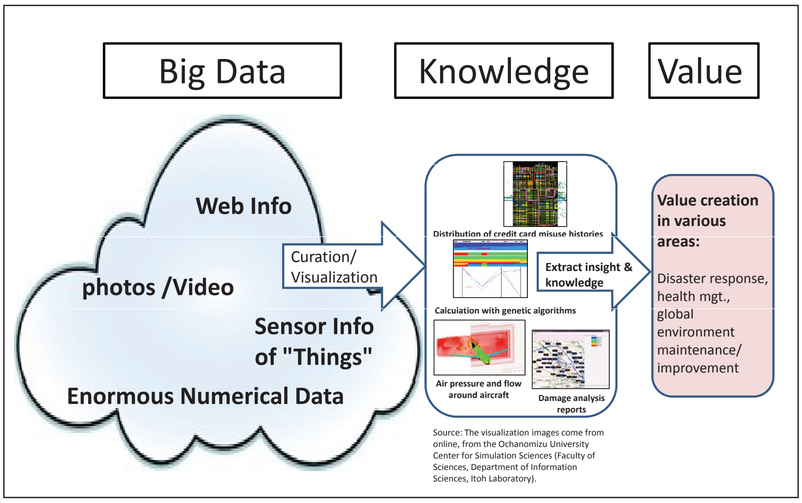

Figure : Creating Value from Big Data

Source: Compiled by the Science and Technology Foresight Center.

4 Design Thinking Education at Universities and Graduate Schools

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Shifts in science and technology innovation policy have come to necessitate better education for instructing society's future innovators. We need to educate workers who can solve problems that overlap multiple fields and who can also discover and assign what the new issues will be. One approach to educating such workers, design thinking education, is attracting attention at universities and graduate schools across the globe.

In design thinking education, a real-world issue is posed to a highly diverse team with members from different fields, who engage in a project to present a proposal to solve the problem. Some universities and graduate schools that have already implemented design thinking education have sent team members off-campus to see and hear about the issue in person, who then return with their experiences and generate ideas toward a solution. The team displays their proposed solution as a prototype and gives a short presentation to explain it. They also make an active effort to present the results of their work to the public.

While in recent years universities and graduate schools around the world have begun introducing design thinking education, there are few curriculums in Japan that explicitly adopt the term "design thinking." Japan should try to understand the intent of design thinking, foster a mentality of actively supporting these initiatives, set up places where the public can experience an embodiment of this mentality and focus on relationships outside academia, and instigate change in education, even if it is only incremental and gradual.

(Original Japanese version: published in September/October 2012)

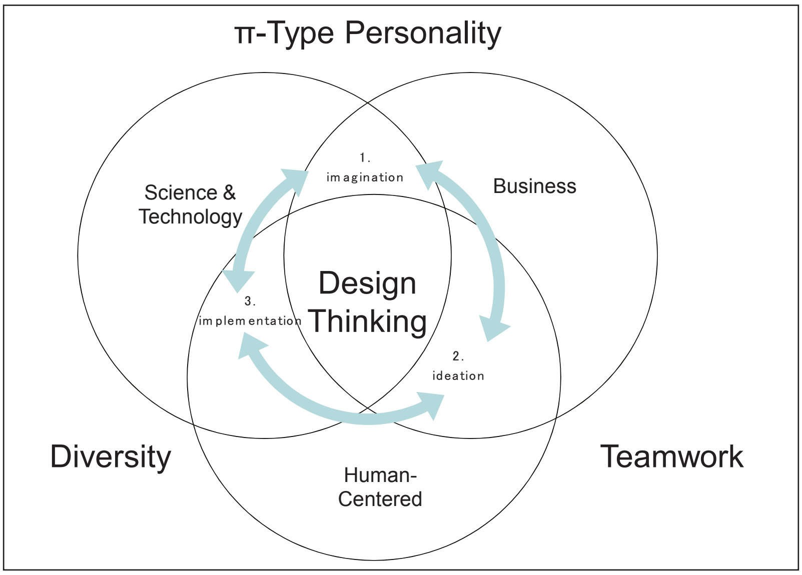

Figure : Design Thinking Education Overview
Compiled by the Science and Technology Foresight Center

5 Building Damage Depending on Earthquake Vibration Period and New Technology Issues

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Both the 2011 Off the Pacific Coast of Tohoku Earthquake (that caused the Great East Japan Earthquake Disaster) and the 1995 Southern Hyogo Prefecture Earthquake (that caused the Great Hanshin-Awaji Earthquake Disaster) claimed many lives and caused enormous damage. However, their damage situations are entirely different. The 2011 Off the Pacific Coast of Tohoku Earthquake (hereafter "the 2011 Tohoku Earthquake") produced catastrophic tsunami damage, but the building damage caused by ground motion was not as serious as that in the 1995 Southern Hyogo Prefecture Earthquake. This was because the ground motion with a period of 1 second or less, which affects buildings little, was predominant in the 2011 Tohoku Earthquake. On the other hand, the ground motion with a period of 1 to 2 seconds, which causes heavy damage to buildings, was predominant in the 1995 Southern Hyogo Prefecture Earthquake (see Figure).

The 2011 Tohoku Earthquake produced "long period ground motion" with a period of 2 seconds or more in the Tokyo metropolitan area and swayed super-high rise buildings heavily. However, there were no serious damages in any super-high rise buildings because they already equipped earthquake-resistant systems such as seismic isolation and vibration damping. In truth, the aftermath of long-continued or repeated long period ground motions on the super-high rise buildings is still unknown and should be studied in the future.

The "slightly short period (1 to 2 sec.) ground motion" and "long period (2 sec. or more) ground motion" could cause damage situations that cannot be truly represented by a single indicator of the current seismic scale. The vibration period of ground motion is considerably affected by not only the hypocenter but also the ground structure and propagation path of seismic waves. Thus, it differs by location even in the same earthquake. Because the slightly short period ground motion damages wooden houses and low- and medium-rise buildings, new evaluation indicators for that may be necessary.

In order to reduce earthquake damage, it is also necessary to achieve mutual collaboration among academic or technological fields, such as seismology, geotechnical engineering, civil engineering, and building engineering, as well as to share and integrate the knowledge in each field, rather than to conduct a study separately in each field.

(Original Japanese version: published in May/June 2012)

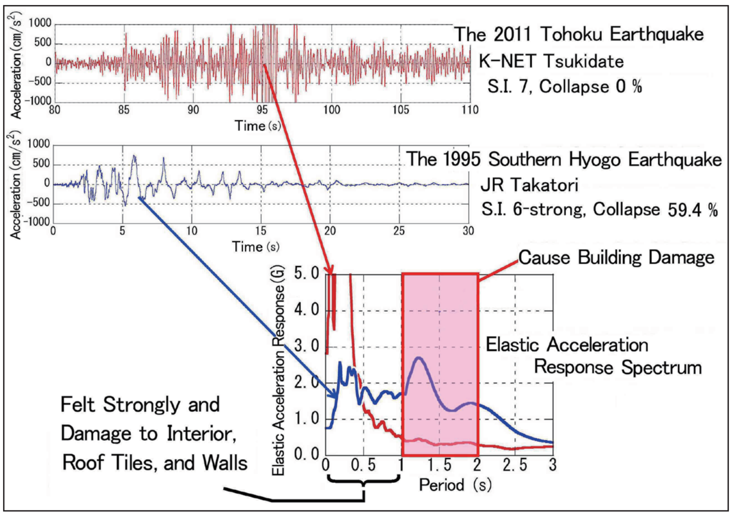

Figure : Comparison of Ground Motions in the 2011 Tohoku Earthquake and the 1995 Southern Hyogo Prefecture Earthquake. (Provided by Y. Sakai)

1

R&D Trends for High-Energy Automobile Capacitors to Hasten CO_2 Reductions

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1 Introduction

Capacitors have become a subject of interest in research and development to build storage systems allowing, for example, exhaust energy recovery and the absorption of small to medium amounts of wasted electricity. These would make automobiles, industrial machinery, renewable energy systems and the like utilize energy more effectively. Japanese industry has proudly created technologies with small environmental impacts, some of which include capacitors, rechargeable batteries and other storage system technologies. These have secured a high degree of potential in global markets. In particular, energy-saving capacitors have become common backup power supplies in electronic devices and other products, and these storage systems are now becoming more widely adopted in devices to reduce CO_2 emissions and conserve energy. Furthermore, our society is demanding that storage systems have higher and higher output and energy capacity.[1, 2]

The automotive sector provides cases of adopting capacitors as backup power supplies in automobile equipment. The industry is examining techniques such as recovering the kinetic energy wasted during braking to provide auxiliary power for the engine.[3] However, we cannot say that we have yet seen the full-scale introduction of capacitor storage system technologies.

Compared to rechargeable batteries such as nickel-hydrogen batteries or a lithium ion batteries (LIBs) employing electrochemical redox reactions, capacitors have high power density. Their short recharge times and ability to instantly discharge give them advantages that include high responsiveness to load fluctuation, a long shelf-life allowing many charge/discharge cycles, as well as good safety and reliability. On the other hand, a capacitor's disadvantage is that it has a lower energy density compared to a rechargeable battery. If a compact, low-cost capacitor could be created with the same energy density or more as an LIB while maintaining the advantages of a regular capacitor, then it could be applied to primary power supplies or regenerative braking in automobiles, with the possibility of further applications in a wide range of storage systems for various other types of industrial machinery. We could expect the result to be a drastic reduction in CO_2 emissions.

This paper addresses the current state of R&D on and the need for high-energy capacitors in automobiles, as well as the direction the materials technology field is heading in to create these capacitors.

2 Strategies for Using High-Energy Capacitors

2-1 Reducing CO_2 Emissions by Popularizing Automobiles Running on Capacitors

Backed by green government policies, the use of hybrid vehicles (HVs), plug-in hybrid vehicles (PHVs) and electric vehicles (EVs) is rapidly expanding. Improving the performance of installed storage systems will be the key to a further policy push encouraging the spread of these technologies. LIBs are currently the most common rechargeable batteries installed in automobiles. Meanwhile, the ability of capacitors to quickly recharge is used for recovering energy, stop-and-go driving and auxiliary power supplies that instantly provide the high output required by automobiles, among other functions. In general, the term "capacitor." often refers to an electric double layer capacitor (EDLC).

Employing storage systems with high output and energy as primary and auxiliary power sources for automobile engines could significantly reduce CO_2 emissions. The rapid popularization of HVs and other such vehicles in Japan has contributed to a declining trend in CO_2 emissions volume, while further incentives to use HVs, PHVs, EVs and the like could

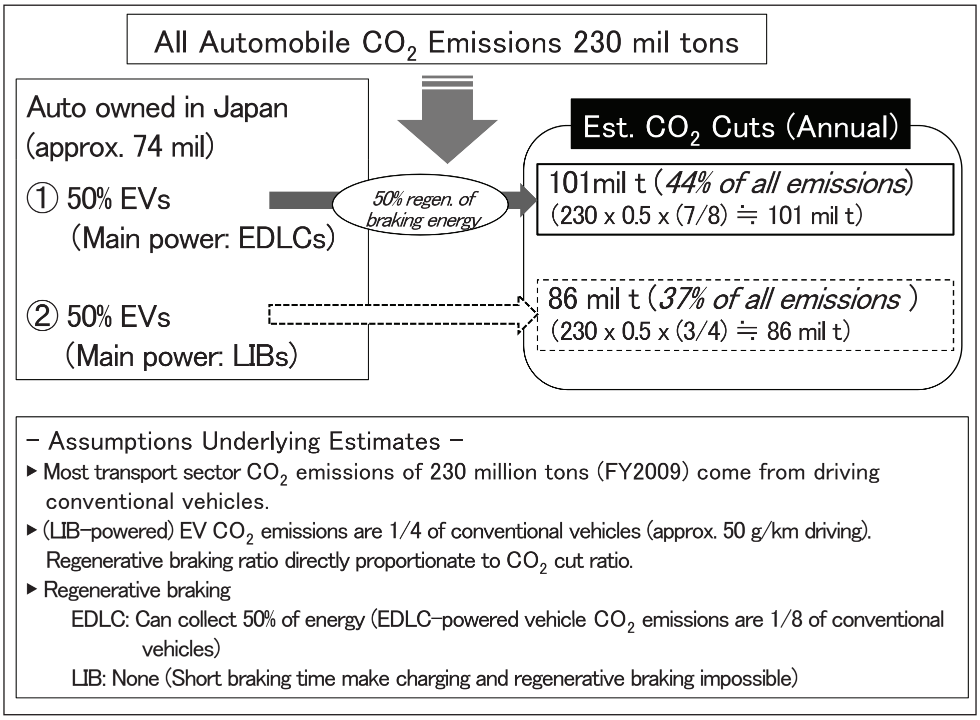

Figure 1 : Estimated CO_2 Cuts Resulting from Greater Use of EDLC-Powered Automobiles

Compiled by the Science and Technology Foresight Center

lead to much larger cuts. "Building a Low Carbon Society," an action plan formulated by the Ministry of Environment, and "Next-Generation Vehicle Strategy 2010,." a report published by the Ministry of Economy, Trade and Industry (METI), set an ambitious target for vehicles equipped with rechargeable batteries such as HVs, PHVs and EVs to account for 50% to 70% of all new vehicle sales in Japan by 2030.[4, 5]

Figure 1 shows a simplified estimate of the CO_2 reductions resulting from the popularization of vehicles running on EDLCs. The spread of vehicles such as EVs, which emit roughly a quarter the CO_2 emissions of conventional vehicles running on fossil fuels (around 50 g/km), would produce a drastic cut in total CO_2 emissions by automobiles. If 50% of all automobiles on the road in Japan (a fleet of approximately 74 million vehicles in FY 2009)[6] were EVs and we assume that almost all CO_2 emissions are produced by the transportation sector (230 million tons in FY 2009), then this would cut total CO_2 emissions by about 37% (about 86 million tons).[8] If we then suppose that the EVs primarily run on EDLCs capable of recovering braking energy, which accounts for roughly 50% of a vehicle's kinetic energy, then total CO_2 emissions would drop by around 44% (around 101 million tons). Even if 50% of all vehicles were HVs (with a conventional engine and an EDLC-powered engine) with EDLCs as their auxiliary power supply, collecting and reusing around 50% of a vehicle's kinetic energy could still reduce total CO_2 emissions by about 25% (58 million tons). This is how estimates show that adopting EDLCs as primary or auxiliary drives for automobiles could result in a vast drop in total CO_2 emissions.

Recovering braking energy, or regenerative braking, is a process in which the main motor's function is converted to that of a power generator, converting kinetic energy (with the exclusion of mechanical/electrical loss, etc.) produced by energy conversion into electrical energy to be stored for later use. It has been postulated that, in theory, it is possible to recover 50% or more of a vehicle's kinetic energy as braking energy.[9, 10] For the time being, a good strategy would be to make large cuts in automobile CO_2 emissions by using the advantageous traits of EDLCs and applying them to energy recovery systems for use as auxiliary drives, to be followed in the future with more powerful EDLC storage that can be used for the instantaneous high output that is impractical with today's LIBs and that can undergo numerous and frequent charge/discharge cycles.

2-2 Options for Capacitors to Run Automobiles

Figure 2 shows a comparison of EDLC and LIB storage performance[3, 11, 12] and the steps to create an ideal storage system for automobiles. This figure simplifies the advantages of EDLCs and LIBs on a 0-100 scale. For example, this scale is applied to EDLC power density and LIB energy density

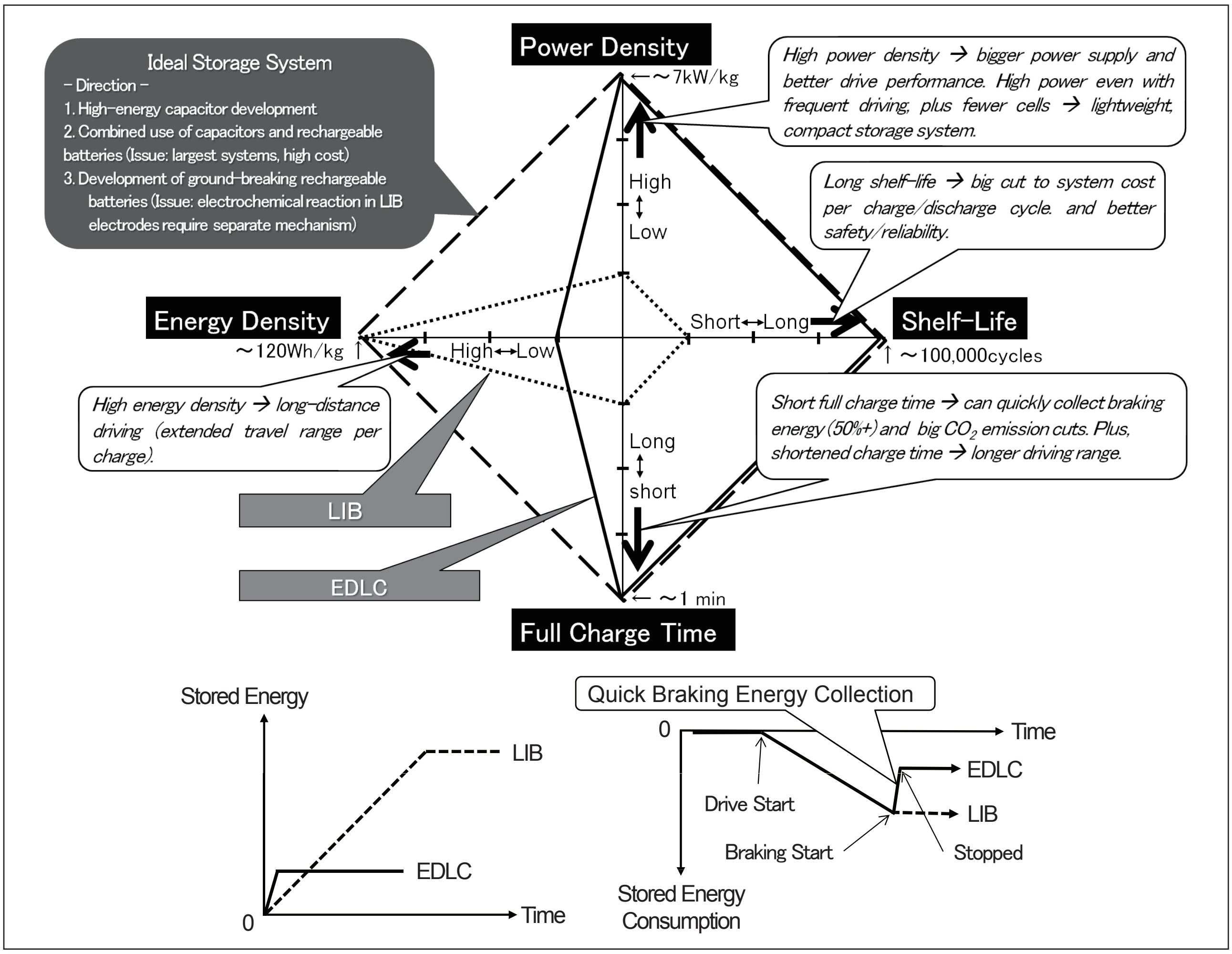

Figure 2 : Comparison of EDLC and LIB Storage Performance--Direction of Ideal Automobile Storage System

Compiled by the Science and Technology Foresight Center

along the horizontal axis. Each attribute's storage performance is assessed at four points along each line. Compared to LIBs, which are superior rechargeable batteries, EDLCs have much higher power density, shorter charge times and longer charge/discharge shelf-life. EDLCs also have advantages that LIBs do not: high energy efficiency (discharge/charge efficiency of 90% or better) due to low heat of reaction on the cathodes, among other reasons; they are very safe and have a low environmental impact because they do not use heavy metals, halides and the like as constituent materials. Supplying resources for constituent materials becomes a worry when carbon materials are used in electrodes. However, EDLCs suffer a serious disadvantage compared to LIBs due to their low energy density, so a major R&D issue is to improve this attribute.

While EDLCs have the perfect power density and charge/discharge cycle shelf-life as main power sources for HVs, PHVs, EVs and so on, their energy density is low compared to rechargeable batteries such as LIBs, meaning that the EDLC would have to be recharged frequently during a long trip. Capacitors' high power density is already used in, for example, automobile idle reduction systems. These capacitors provide the high current needed to frequently switch the engine on and off.[3, 13] Accordingly, the use of capacitors in HVs, PHVs and EVs that run on rechargeable batteries could lead to smaller rechargeable batteries that move the vehicle and allow the vehicle to very efficiently and instantaneously recover power from the energy wasted during braking. Converting this recovered energy into electrical energy, which is instantly stored in a capacitor for later use in moving the vehicle, could further reduce CO_2 emissions. To expand the use of capacitors as auxiliary power sources, for the time being we should first promote applications that utilize capacitors' high power by using them in conjunction with rechargeable batteries. Then, further on in the future, if the energy density of capacitors reaches or exceeds that of LIBs, these high-energy capacitors could potentially perform as primary power sources for automobiles and replace LIBs.

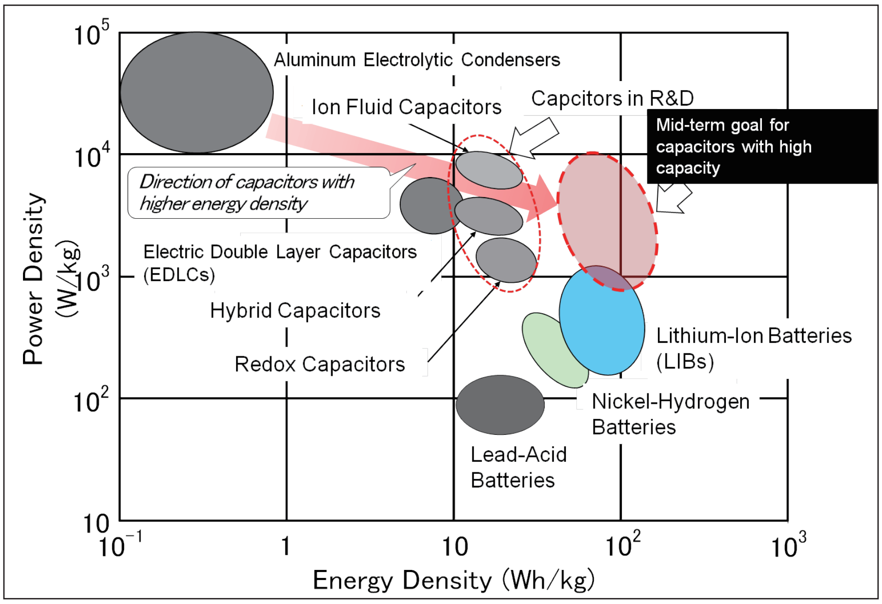

Figure 3 : Storage System Power/Energy Density Relationships and Mid-Term High-Energy Capacitor Goal

Compiled by the Science and Technology Foresight Center

2-3 Target Attributes for High-Energy Capacitors

Figure 3 shows the relationship between power density and energy density over weight for various storage systems.[3, 8, 9, 13-15] The storage systems are capacitors that mainly gain electrical energy from the physical absorption and desorption of ions and rechargeable batteries that gain electrical energy via electrochemical reactions on the cathodes during the storage and discharge of electrical energy. EDLCs operate in volts (V). Their attributes, which allow them to store a large amount of electrical charge with low voltage and their usability over many charge/discharge cycles, have led to the use of ultra-small and small EDLCs in many electrical circuits with low operating voltage. Some examples of systems that use EDLCs in this manner are backup memory power sources in audio-visual and mobile devices, solar-powered watches and emergency gas valves. These EDLCs were first commercialized and mass produced in Japan during the 1970s.

Capacitors developed thus far with relatively high energy density include: redox capacitors that use intercalation reactions (the insertion of ions between the crystal structures of electrode materials) or redox reactions in the cathode/anode or both; hybrid capacitors that use charge transfer reactions in a rechargeable battery's electrode (either the cathode or anode); ionic fluid capacitors that use ionic fluid as an electrolyte for creating high voltage. For example, a lithium-ion capacitor (LIC), which is a hybrid capacitor that uses activated carbon on the cathode and graphite pre-doped with lithium ions on the anode, is a leading candidate for becoming a High-Energy capacitor.[1, 3, 11, 13] It should be noted that redox capacitors, LICs and the like are also collectively called electrochemical capacitors. However, these capacitors that are still in the R&D phase and have an energy density that is an order of magnitude less than those of LIBs.

Figure 3 shows the range of medium-term targets for the power density and energy density that high-energy capacitors should aim for. For the medium-term, we should set a target of reaching an energy density level equivalent to today's LIBs. To do this, R&D should devote efforts focused on electrodes and electrolytes. In its long-term roadmap, the New Energy and Industrial Technology Development Organization (NEDO) has set a target of vastly increasing the energy density of rechargeable batteries that employ electrochemical reactions on electrodes to 500 Wh/kg or better. However, considering how capacitors compete against LIBs so well in terms of their other attributes, the first R&D step should be to try and create capacitors with an energy density equivalent to today's LIBs.

Capacitors are also applied to fields outside of automobiles such as laser printers and copy machines, for which capacitors negate the need for standby power and make the equipment for use in a short time by quickly discharging a high current; as large-scale emergency power supplies for factories manufacturing industrial goods; and as uninterruptible power

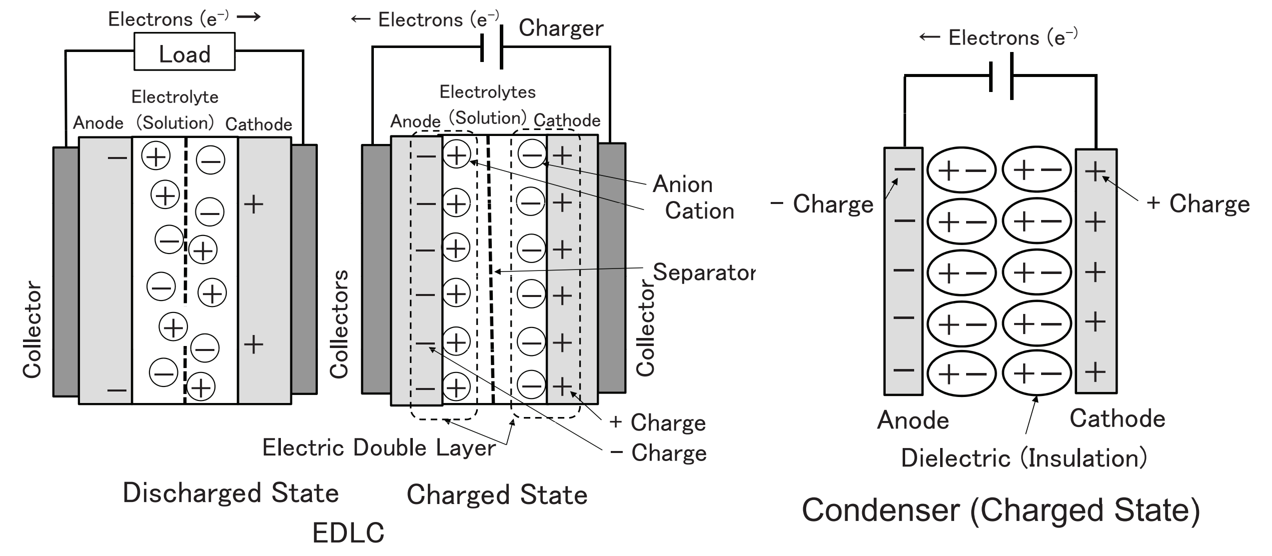

Figure 4 : Basic Storage Mechanisms of EDLCs and Condensers

Compiled by the Science and Technology Foresight Center

supplies that quickly discharge a high current. As for current market demand for these systems in terms of the attributes of capacitors versus today's LIBs, it is around three to ten times higher for power density, but around one-tenth lower for energy density.[16] These attribute levels are somewhat far from the mid-term targets proposed in Figure 3, but capacitors continue to be used for the abovementioned purposes. However, it goes without saying that using capacitors with an even higher energy density would make these applications even more beneficial, such as by lengthening power supply lifespan for these systems.

3 Capacitor Storage Mechanisms

Figure 4 shows a comparison between the basic storage mechanisms of an EDLC and a condenser. An EDLC cell generally comprises a pair of electrodes (a cathode and anode) with activated carbon and other materials with a large specific surface area and electrolytes (an electrolyte solution), along with a separator and a current collector. Like a capacitor, a condenser is generally an electrode region where charge is collected and comprises two dielectric materials (oxides such as tin, aluminum or tantalum) between two electrodes. Meanwhile, an EDLC essentially does the same by accumulating positive charge (i.e. electron holes) in the cathode and negative charge (electrons) in the anode by recharging. The two charges and ions of opposite charges line up against and are attracted to each other near the surface of the electrodes in the electrolytes. The ions act equally upon electrodes of the opposite charge, and an electric double layer comprising charge and ions forms in

[NOTE 1] In Japan, a condenser usually refers to an electrical circuit component. Outside Japan, both condensers and capacitors are called capacitors. Recently, capacitors with advanced functions have been called supercapacitors.

[NOTE 2] Farad (F) is a unit of capacitance. 1 F is defined as "the potential between two conductors created by 1 V of direct voltage during the release of electrical charge carried by 1 A (ampere) of current over 1s (second)." The potential (C) is represented by the equation $C=\varepsilon S/d$, in which ε is the permittivity of the dielectric between the electrodes, S is the surface area of the electrodes and d is the distance between electrodes.

[NOTE 3] In a condenser, electric polarization occurs within the electrical field that enters the insulation between the electrodes, and the electrodes accumulate positive and negative charge. The event that creates electric polarization is called a dielectric phenomenon. The material that causes this phenomenon is called a dielectric (if the insulation is focused on the dielectric phenomenon). A typical condenser is an aluminum electrolytic condenser (a cell structure wrapped in a sheet impregnated with an electrolyte solution within an aluminum oxide coating), but the energy density of an aluminum electrolytic condenser, which is the highest among all condensers, is extremely low compared to an EDLC at only around one-hundredth (see Figure 3).[17]

the interface region between the electrolytes and the cathode/anode. In an EDLC as well, the region where ions and charge are separated from each other at a nanoscale distance is equivalent to a dielectric. The capacitance is proportionate to the surface area (S) of the electrodes and the distance (d) between the electrodes (charge and ions) is inversely proportionate. However, an EDLC can achieve greater capacitance than a condenser with an electric double layer.

As with a condenser, the capacitance accumulated in the electric double layer is represented as C (measured in farads [F]). The stored energy (E) is calculated with C and operating voltage (V) as in the equation below.

$$E=0.5CV^2$$

Here, C, is calculated according to the equation below, with the permittivity of the dielectric between the electrodes represented as ε.

$$C=\varepsilon S/d$$

Large capacitance and high operating voltage are needed to condense high amounts of energy per unit weight/volume.

During charging, ions are absorbed by the electrode surfaces. During discharge, the charge within the electrodes is released while the ions break free from the electrode surfaces. As a rechargeable battery does, there is no accompanying electrochemical reaction (the release/capture of electrons when oxides break down/form due to redox reactions). Thus, rapid charging and discharging are made possible by physical charging and discharging performed merely through the absorption and desorption of ions. Because a capacitor's charging and discharging is performed only via the movement of the ions gathered on the electrode surfaces, it can quickly switch from charging/discharging to large power output via a high current. There are few side reactions during charge/discharge. This gives a capacitor the advantages of no degradation of electrode materials or electrolyte solutions, long shelf-life and superior safety and reliability. On the other hand, because the application of a certain amount of voltage causes electrolysis if the electrolyte is a solution, the rated voltage of current EDLCs is between 2.5V and 3V.[3, 13]

4 Policies and Issues for Development of High-Energy Capacitors

4-1 Creating Electrode Materials with High Capacitance and Cells with High Operating Voltage

Figure 5 is a structured depiction of the main approaches for creating a capacitor with high energy density. These approaches are broadly divided between the creation of electrode materials with high capacitance and cells with high operating voltage.[3,11-13,18,19] Experiments are currently underway to create electrode materials with high capacitance by substituting activated carbon with carbon materials, metal oxides, conductive polymers and the like with structures that are regulated on the nanoscale, which then increase capacity through charge transfer. Because there is a limit to the capacitance an electric double layer can have on the surface of a carbon material, further increasing the number of pores in accordance to the ions absorbed, in order to increase the capacitance per unit weight of the electrode material, will not necessarily raise the material's per-volume capacitance. Inorganic materials, polymers and various other materials are known as electrode materials, but ruthenium oxide can reportedly be used to create materials with a capacitance of over 1,000 F/g. An example of research to increase the utilization rate of charge and ions in electrodes and improve stability over numerous charge/discharge cycles is that done on oxide electrode materials, which has used the material three-dimensionally to increase their surface area (S), accomplished by cellular and layered material structures.[11, 12]

The energy (E) accumulated by a capacitor increases in proportion to the square of operating voltage (V), so a high-energy capacitor would result in high operating voltage. The approaches to creating cells with high operating voltage are divided into creating those with high withstand voltage in their electrolytes and those with a hybrid electrode composition. One known approach for creating cells with high operating voltage is to increase voltage from the breakdown of the electrolyte solution by using electrolyte materials such as ionic fluid with a wide potential window (the potential range in which the electrolyte solution will not undergo a redox reaction). Electrolyte solutions are

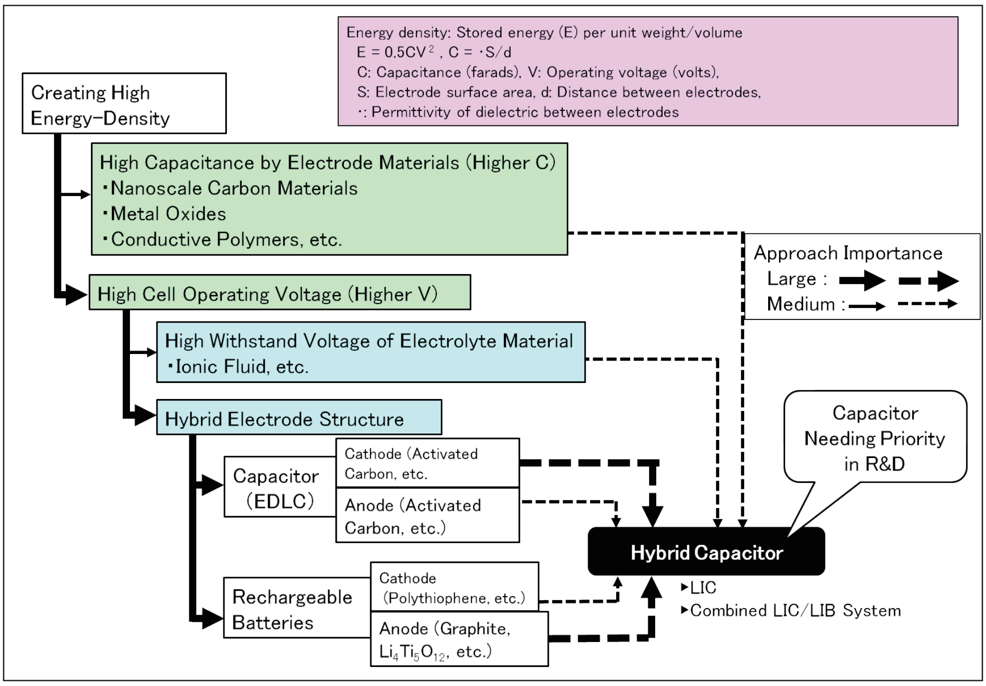

Figure 5 : Main Approaches to Developing Capacitors with Higher Energy Density

Compiled by the Science and Technology Foresight Center

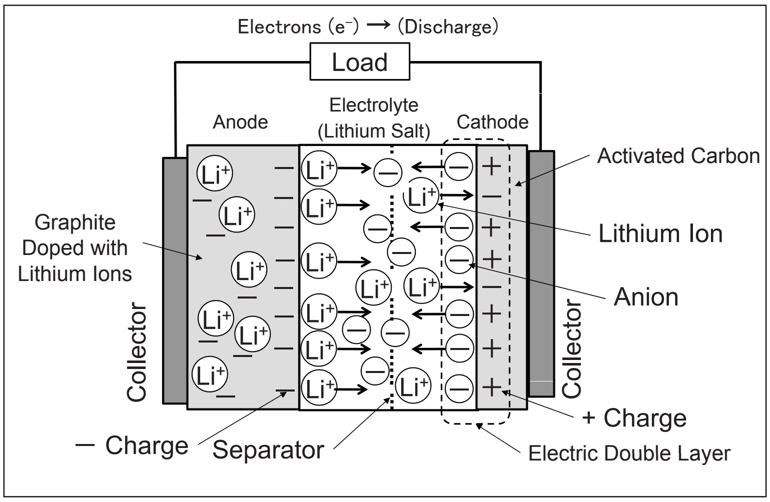

Figure 6 : LIC Cell Discharge Mechanism

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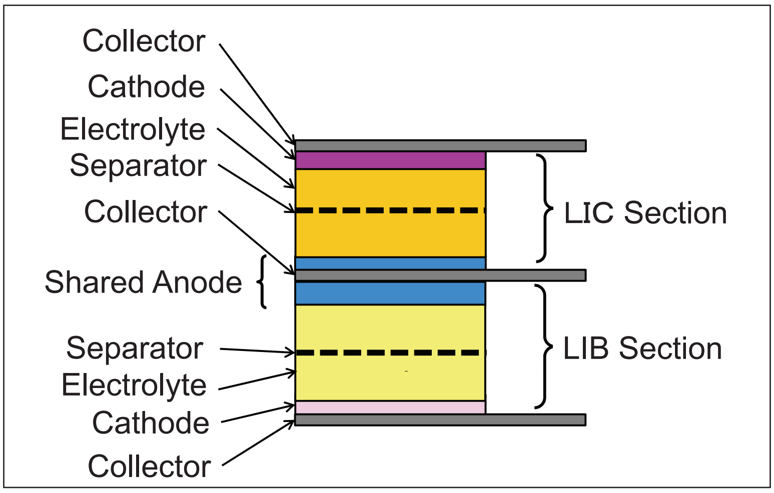

Figure 7 : Schematic of a Combined LIC/LIB Storage Cell

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classified as aqueous and non-aqueous. Because the potential window of non-aqueous electrolyte solutions (around 2.5 V) is relatively wide compared to aqueous electrolyte solutions (around 0.8 V), currently, non-aqueous electrolyte solutions employing, for example, propylene carbonate as a solvent and ammonium salt as a supporting electrolyte, are primarily in use.[3, 11, 12]

At present, the approach for developing high-energy capacitors thought to be the most effective is to create cells with high operating voltage with a hybrid structure combining a capacitor with a rechargeable battery, using the rechargeable battery electrode as either the cathode or anode. A prototype high-performance capacitor that nearly reaches the energy density of an LIB has been created. It is an LIC with a cell comprising a rechargeable battery anode and a capacitor cathode (see Figure 6).[20, 21] For the time being, R&D will continue in order to achieve the creation of high-energy capacitors by using this cell structure with LICs or combined cells that blend the superior attributes of both LICs and LIBs (see Figure 7).

4-2 Hybrid Capacitors

The abovementioned LIC made from a combined cell with a hybrid structure is a storage system that incorporates the advantages of an EDLC and LIB. Figure 6 shows the discharge mechanism in an example of an LIC cell using activated carbon on the cathode and graphite pre-doped with lithium ions on the anode. In an LIC, the cathode forms an electric double layer and charges and discharges with a physical mechanism, while the charge/discharge mechanism of the anode works through a lithium electrochemical reaction. That is to say, it is a storage mechanism combining the functions of an LIB anode and an EDLC cathode. An LIC has a higher energy density than an EDLC because the anode's capacitance is increased by doping the anode with lithium ions, thus allowing the cell voltage to rise from 2.5 - 3 V to around 4 V. The LIC’s power density, charge/discharge cycle shelf-life and other attributes are equal to an EDLC’s. It is also very safe because self-discharge is small and it performs well at high temperatures. In the anode, lithium ions undergo intercalation. During charge and discharge, the electric potential is fixed near the redox potential of lithium. Meanwhile, the potential in the cathode, an activated carbon electrode, changes. During discharge, the lithium ions face the cathode and the negative ions face the anode, while the reverse happens when charging.[3, 13]

LICs that utilize the high power, long shelf-life and good safety of EDLCs while increasing energy density to the level of a lead-acid battery could potentially be used as primary power sources for HVs, PHVs and EVs. LICs employing lithium salt in an electrolyte solution are already in practical use in disc capacitors,[22] but they are not yet fully practical in layered, rolled up and other types of large capacitors due to the difficulty of lithium ion pre-doping, among other reasons. Issues concerning LICs include increasing the cell’s overall electromotive force, increasing overall cell capacitance by using electrode materials with low voltage dependence for the electrical charge, and creating high energy by employing electrode materials that balance electric potential for the electrical charge.

Furthermore, an example of developing a combined storage system is one that blends an LIC and LIB inside a cell.[23] As Figure 7 shows, this is a storage system that blends an LIC cell with an LIB cell by sharing the anode via the collector. The LIC section performs rapid charging and discharging, while the LIB section performs long-term charging and discharging, thus allowing the storage system to produce instantaneous as well as sustained power. The prototype cell (a flat, rolled up, 10 Wh cell) has a power density of 3 kW/kg and an energy density of 60 Wh/kg, nearly that of an LIB. This is how combining an LIC and LIB within a cell can improve on the LIB’s weakness with the quick charging and discharging of an LIC, while making up for the LIC’s weakness with the LIB’s long-term electrical power storage. This approach to creating a combined storage system could be one way to create a high-energy capacitor.

5 Materials Technology to Create High-Energy Capacitors

R&D into new electrode materials will need to surmount various issues such as those concerning effective operation at low and high temperatures, tolerance to damage due to overcharging and long-term retention of charged energy in order to create the high-power and high-energy capacitors of the future. This R&D will likely be conducted on carbon materials, inorganic materials, polymers and other materials. Meanwhile, even higher withstand voltage, greater electric double layer capacitance, a wider range of operating temperatures and other improvements will be demanded of electrolytes. R&D is now underway on ionic fluids, solid electrolytes and other materials with better properties than combustible electrolytes. The following sections discuss R&D trends in materials technology that will be essential for creating high-energy capacitors.

5-1 Electrode Materials R&D

As Figure 5 shows, the main approaches to giving capacitors high energy density through R&D into materials technology include carbon materials with structures regulated on the nanoscale, metal oxides to exceed the capacitance of carbon materials and polymers capable of storing large amounts of charge.

(1) Carbon Materials with Nanoscale Structures

Carbon materials have long attracted attention as electrode materials. The reason is that regulating their structures on the nanoscale can ensure a wide surface area and achieve high capacitance. Electrodes that employ activated carbon are formed with porous structures with large electric double layer capacitance that is maximized relative to weight or volume. Activated carbon pores are pathways for absorbing and desorbing ions that help diffuse the ions, thus playing a role in improving ionic conductivity. Because carbon formed by activated carbon has low self-discharge, it has the optimal weight of oxygen-bearing compounds such as hydroxyls and carbonyls. The electron conductivity of activated carbon is inferior to that of graphite, so the resistance at the edges of its constituent particles reduces charge/discharge speed.[3,13] Thus, activated carbon needs better electron conductivity as an electrode material. Combining activated carbon with graphite particles possessing good electron conductivity as well as with graphite particles and carbon nanotubes (CNTs) is being investigated.

Furthermore, the CNTs under consideration as capacitor electrode materials are mainly single wall CNTs (SWCNTs) with a wide surface area per unit weight, thus giving them a large electric double layer capacitance per unit weight (100-200 F/g). Because SWCNTs have surfaces that absorb ions well and high electron conductivity, they can handle rapid charging and discharging with high current. This allows them to act as an electrode material for high-power capacitors. However, when a CNT aggregate, called a bundle, forms, the surface area available for forming electric double layers and the electric double layer capacitance per unit volume are reduced, thus lowering electron conductivity. In addition, there are problems such as amorphous carbon byproducts in CNTs and the insertion of catalytic particles to grow CNTs. R&D on capacitors that employ SWCNTs is still ongoing. Other than SWCNTs, research is also being conducted on carbon nanofibers (CNFs).

Researchers at the Brookhaven National Laboratory in the United States have discovered the nanoscale graphene structure of graphene with a wide specific surface area (2,630 m^2/g) that absorbs charge. They are trying to develop capacitors with an energy density equivalent to lead-acid batteries and that can charge and discharge quickly.[24] This graphene has a three-dimensional network structure possessing numerous holes (void space 0.6-5.0 nm) formed by a curved wall as thick as a single carbon atom. Reportedly, the researchers are conducting computer simulations concerning the process of three-dimensional network formation in graphene, and are investigating the nanoscale structure of the holes with high-resolution electron microscopes, in order to make it possible to lay out the holes' dimensions and structure. Figure 8 shows a reported case in which electrodes were made by inserting CNTs between layers of graphene.[25] This electrode structure absorbed large amounts of ions in the electrolyte solution on the graphene's surface. Furthermore, it used the ionic fluid within the electrolyte solution to succeed in achieving an energy density equivalent to a nickel-metal hydride battery. However, it may be possible to improve energy density in the same manner by dispersing and blending graphite fragments and single-layered CNTs rather than through a combination of graphene and SWCNTs.

(2) Metal Oxides

Using metal oxides as electrode materials in capacitors should have the benefit of allowing the capacitor to achieve high capacitance compared to carbon materials. Compared to activated carbon, the capacitance accumulated with a metal oxide has been reported to be approximately 10 times greater. Hydrous ruthenium oxide ($RuO_2 \cdot nH_2O$) is a typical electrode material that collects and releases charge through redox reactions and can be used to build capacitors with large charge/discharge capacity. Until

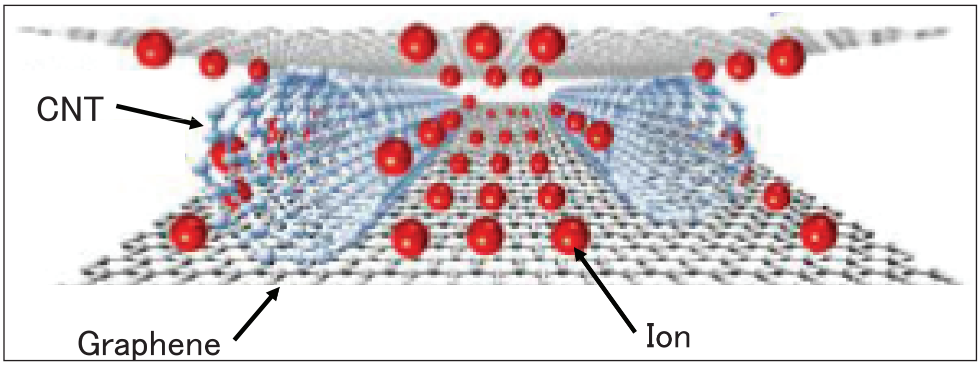


Figure 8 : Schematic of Electrode with CNT Distributed between Graphene Layers for Greater Ion Absorption

Figure in Reference #25 recreated by the Science and Technology Foresight Center

now, blending this material's nanoparticles and thinned forms of it with dissimilar metals, carbon materials and conductive polymers has been investigated. High capacitance densities of 600 to 1,200 F/g have been reported in all of them.[11, 12] While ruthenium is not considered a rare metal, reserves are not plentiful and supplies are not steady. It would be preferable to use cheap metal oxides with a steady supply in order to provide a large volume of capacitors. Metal oxides such as manganese dioxide (MnO_2, capacitance 480 F/g) and nickel oxide (NiO, capacitance 300 F/g) also reportedly have a comparatively high capacitance density, but none have yet been found that exceed ruthenium oxide's. Issues common to all capacitors that employ metal oxide electrodes include inadequate electrode durability and fluctuations in charge due to charge/discharge speed.

One reported technique to combine metal oxides with carbon materials is to highly disperse nanocrystal grains (5-20 nm) of lithium titanate ($Li_4Ti_5O_{12}$) and combine them with nanocarbons (CNF, CNT) in an anode that is then used to create an LIC with an energy density approximately three times greater than an EDLC's. Figure 9 shows the properties of an LIC comprising an anode of nanocarbons with dispersed $Li_4Ti_5O_{12}$ nanocrystal grains and a cathode of activated carbon, as well as a high-resolution transmission electron microscope image of the anode's material.[26] Improving electron conductivity in the anode with nanocarbons and expanding capacitance by employing an anode with $Li_4Ti_5O_{12}$ nanocrystal grains makes it possible to achieve higher energy density with a flat anode potential of around 1.6 V. Using $Li_4Ti_5O_{12}$ eliminates the need to pre-dope with lithium ions and ensures that the LIC is safe by operating within a potential range with no electrolyte breakdown.

(3) Polymers

Using polymers as electrode materials in capacitors should be able to achieve high capacitance by storing and releasing large amounts of charge through reversible redox over a wide potential range. Such polymers include polyaniline, diaminoanthraquinone and cyclic indole trimmers, which power hydrogen ions within a solvent, and polyfluorophenylthiophene and polymethylthiophene, which provide power within a non-aqueous electrolyte solution. Using these polymers as electrode materials can achieve capacitance density of 200-300 F/g, several times greater than an activated carbon electrode.[11] However, these polymers' capacitance is relatively low compared to metal oxides. Additionally, an issue with these polymers is the deterioration due to excessive oxidation and hydrolysis accompanying numerous charge/discharge cycles, resulting in lowered capacitance density.

An example of a combination used to create a prototype LIC is one comprising a conductive polymer membrane of polypyrrole, polythiophene and polyaniline for the cathode, activated carbon pre-doped with lithium ions as the anode, and, as in existing EDLCs, an organic solvent containing boron quadrafluoride ions (BF_4^-) for the electrolyte solution. This LIC achieves an energy density of 60-80 kWh/kg, nearly that of an LIB's, and a high power density of 7 kW/kg.[20, 21] Figure 10 shows a schematic of the mechanism for absorbing negative ions in a cathode employing a conductive polymer membrane. The cell's capacitance is expressed as the reciprocal of the sum of the reciprocal of each electrode's (the cathode and anode) capacitance, thus increasing the energy density of each as their capacitance rises. In addition to increasing anode capacitance with lithium ion pre-doping, using conductive polymers also

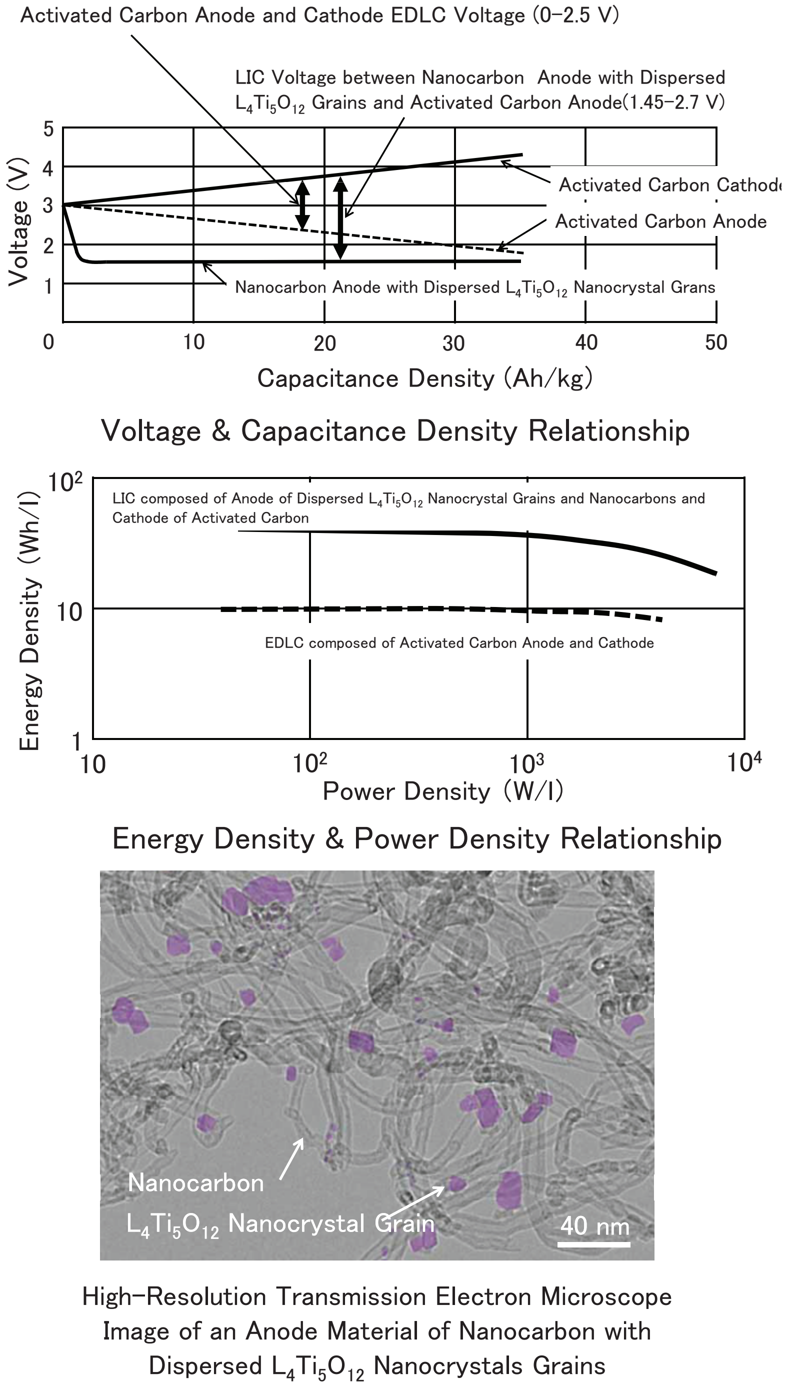


Figure 9 : Properties of an LIC composed of Nanocrystal with an Anode of Dispersed $Li_4Ti_5O_{12}$ Nanocrystal Grains Nanocarbons and a Cathode of Activated Carbon,and High-Resolution Transmission Electron Microscope Image of the Anode Material

Figure in Reference #26 recreated by the Science and Technology Foresight Center

raises cathode capacitance. In the cathode, the fine conductive polymer membrane (thickness approx. 50 μm, polymer radius approx. 0.5 nm) forms on the surface of the collector's aluminum foil (width approx. 30 μm) through electrolytic polymerization. Since many BF4- ions are three-dimensionally inserted into the membrane, a high capacitance is achieved. Even with the use of conductive polymers in the electrodes, it could be possible to use this type of LIC as the primary power source for automobiles if resistance to electron conduction in the electrodes can be reduced and the deterioration caused by numerous charge/discharge cycles over a long period of time and rapid charge/discharge can be lessened.

5-2 Electrolyte Materials R&D

As Figure 5 shows, R&D is being conducted on electrolyte materials to achieve high withstand

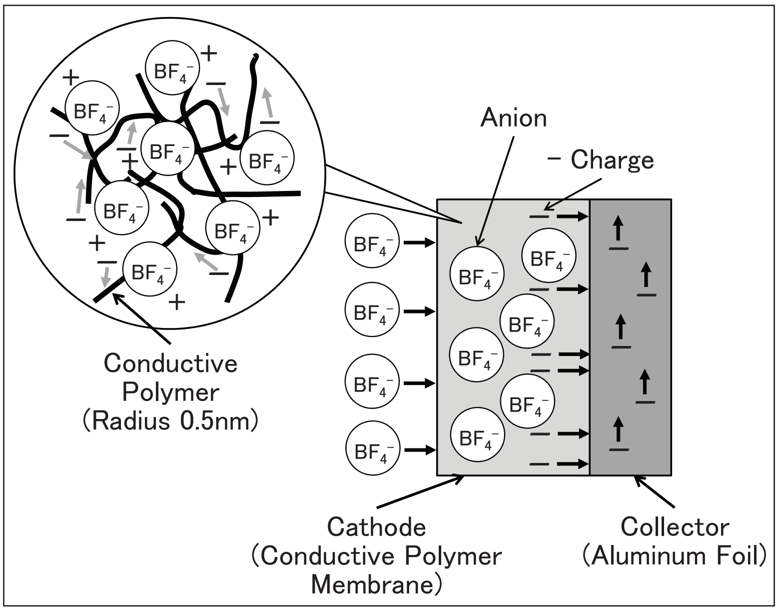


Figure 10 : Negative Ion Absorption Mechanism in a Cathode Employing a Conductive Polymer Membrane (Charged State)

Figure in Reference #20 recreated by the Science and Technology Foresight Center

voltage and give a cell a high operating voltage while maintaining high-speed charging and discharging inside a capacitor with a high energy density.

(1) Ionic Fluid Electrolyte Materials

An ionic fluid is a liquid salt with both positive and negative ions that retains liquid form even though it does not contain a solvent. These fluids can be organic or inorganic. Their properties include flame-retardance, non-volatility and high ionic conductivity (10^{-3}-10^{-4} s/cm). EDLCs that employ ionic fluids are very safe because they can prevent fires caused by leaking electrolyte solution. Typical organic salts in ionic fluids include imidazolium salts, pyridinium salts and aliphatic quaternary ammonium salts as positive ion ingredients. Known negative ion ingredients are inorganic materials such as BF_4^- and hydrogen hexafluoride ions (PF_6^-) and fluoride-containing organic positive ions such as $CF_3SO_3^-$ and $(CF_3SO_2)_2N^-$. Ionic fluids retain their liquid form at room temperature because their structure makes it difficult for them to crystalize and they have little stabilization energy. Ionic fluids have a wide potential window (around 6.0 V) and are electrochemically stable, so they can be used in EDLCs to broaden their operating voltage range. Ionic fluids have been successfully used to broaden a cell’s operating voltage range to 3.0 V while also suppressing internal resistance.[3, 17]

A disadvantage of ionic fluids is that while their melting point is lower than normal salt, their viscosity is higher than an organic solvent electrolyte, even at room temperature. They are also inconvenient for high-speed charging and discharging. In addition, other problems that have been cited include low ionic conductivity and susceptibility to transformations due to redox reactions at low temperatures. They are also difficult to crystallize, making it easy for them to become a salt with high bulk density. While a certain amount of ionic radius maintains ions’ dissociation degree, if they are too big then they cannot enter the electrode pores and form an electric double layer. Thus, electrodes with pores must be combined with ionic fluid containing ions of the appropriate size. At present, organic solvent electrolytes with organic solvents added to ionic fluid are used. However, using a combustible solvent will take away from the ionic fluid's incombustibility. Materials that do not require the addition of solvents and the like and which can charge and discharge at high speed are needed.[3, 17]

(2) Solid Electrolyte Materials

By not using liquids as electrolyte materials, one can create a storage system that will not leak and that has good durability and safety. However, capacitors have to maintain high ionic conductivity and sustain rapid charging and discharging. With this in mind, gel combining polymers, electrolytic salt and a plasticizing agent can be a solid electrolyte material. Studies are underway for LIB applications by using solid electrolyte polymers blending a polyethylene oxide polymer with electrolytic salt in capacitors, as well as a polymer gel of disulfonate that has been the subject of recent research. If the gel can be kept at the right hardness, then this electrolyte can also play the role of the separator between the electrodes. The result is that making the electrolyte region thin and arranging many cells within a series can create a compact, powerful capacitor, even at high voltage. Moreover, lithium-ions travel quickly through inorganic solid electrolytes.8 However, a difficult hurdle for inorganic solid electrolytes to overcome in capacitors is that they must allow both positive and negative ions to move through the electrolyte.[11,27]

5-3 Mechanism Identification Research

Looking at the long term, R&D into LICs with high energy density is ongoing and electrode and electrolyte material techniques that would be effective with regards to LIBs with rapid, high power output and high-energy are being investigated. Electrode materials garnering attention include layered oxides, olivine fluoride, silicates and sulfur for a cathode with high electric potential and high capacitance; and sulphides, silicon and lithium metals for an anode with low electric potential and high capacitance.[8] It would probably be effective to use these electrode materials by analyzing intercalation reactions that the ions cause inside electrode materials, which would then be referenced for governing structures on the nanoscale. Meanwhile, electrolytes need to contain many ions, conduct quickly and be as dense as possible on the side of concentration to reduce the ions' dissociation degree. Furthermore, things that solvents which break down electrolytes need to do well include dissociating ions and being electrochemically affected by redox reactions.

Structural analysis of the constituent materials of cells, along with electrochemical analysis and assessment based on compositional analysis, could be faster ways of discovering charge storage mechanisms that can bring the energy density of capacitors up to LIBs'.[8] An effective approach could be for universities and other institutions to implement these sorts of projects related to the constituent materials of capacitors and to use the results for continued R&D in the private sector.

6 International Trends in the R&D and Commercialization of Capacitors

6-1 R&D and Commercialization of Capacitors in the U.S., China and South Korea

In the U.S., four of the Department of Energy's national laboratories and thirteen companies were actively engaged in the Ultracapacitor Program starting in 1992, which shut down in 1998 before achieving its goals. Although thereafter the federal government and other entities were unable to put together large budgets for capacitor technology-related projects, the Department of Energy has supported small-scale R&D. However, the number of papers written by university and national laboratory researchers on subjects like capacitor electrode materials is increasing. Companies are devoting their attention to capacitors with even greater energy storage. There is great interest in important technologies outside of automobiles, such as uses in medicine, a field that demands top-level reliability, and for auxiliary power sources that supplement compact, high-output power sources. LICs are using lithium manganese oxide ($LiMn_2O_4$) are mass-produced.[22, 28]

In China, buses equipped with capacitors (around 100 kWh) have been used in Shanghai's public transportation network since 2006. Charging stations are set up at every bus stop so they can recharge as passengers get on and off and the buses do not require recharging at other times (range of around 4 km per charge; recharge time of around 30 sec). Capacitor buses also ran through the venue for the 2010 Shanghai World Expo. These two examples are large-scale experiments on the use of capacitors. Although the capacitors are made by Chinese companies, they incorporate technologies from companies such as those from the U.S. that manufacture automobile capacitors.[28, 29] A joint project between Japan and China installed 100-kWh EDLCs to absorb power and help deal with output fluctuations from solar power.[30]

In South Korea, R&D on storage systems is mainly conducted by industry, with government backing. A national project developed high-capacity LIBs and EDLCs from 2004 to 2009. The government enacted the Low-Carbon, Green Growth Basic Law and formulated its Green New Deal policy in 2009. It also formulated the Science and Technology Basic

Plan (the 577 Initiative) at the end of 2008. The government listed "Next-generation Batteries and Energy Storage/Conversion Technology" as one of the key technologies to teach the country's youth in its policies prioritizing the "Promotion of Research and Development on Global Issues."[31] Meanwhile, for a five-year period beginning in 2005, industrial, government and academic research institutes promoted R&D projects on high-energy capacitors for HVs worth around 400 million yen annually. South Korea has a smooth arrangement for projects to receive government subsidies and assistance from venture capital. There are companies in the country already manufacturing high-capacity LICs.[22, 28] We can surmise from this that the pace of R&D in countries like the U.S. and South Korea has slowed somewhat in the 2000s.

6-2 R&D and Commercialization of Capacitors in Japan

Japanese industry has led the market ever since a Japanese company commercialized the first disc EDLC in 1978.Currently, Japanese, American, South Korean and Taiwanese firms account for approximately 70% of global EDLC production. Demand for LED disaster lights and other equipment using EDLCs rose after the Great East Japan Earthquake and imports of EDLCs from South Korea and China to Japan skyrocketed. In recent years, the use of advanced mobile equipment with ultra-small EDLCs has spread. Meanwhile, combined LICs were commercialized, mainly in Japan, in 2009. Capacitors with all manner of capacity rates have since been used in mobile equipment, household appliances, delivery robots and more. Supplies of EDLCs and LICs have been low for the past few years and all companies in the market are ramping up production. However, some of their customers have announced plans to produce their own capacitors. Furthermore, new companies continue to enter the business alongside the more established condenser makers.[22]

The Demonstration Study of New Power Load Equalization Methods, which was conducted from 1997 to 2000 and performed R&D on storage systems to equalize solar power generation output, was the first effort to use capacitors in an energy system. Since 2000, development, mainly with the goal of HV applications, has continued under the framework of "Strategic Development of Energy Use Rationalization" and the like. This development has produced prototype storage systems for HV passenger vehicles and buses.1 Since then, various projects to promote research on industrial technology have also continued with capacitor-related R&D.

One of the important green innovation issues specifically mentioned in the 4th Science and Technology Basic Plan is the promotion of highly efficient energy use with the goal of developing and popularizing electricity control systems through, for example, rechargeable batteries in next-generation automobiles. This includes R&D on subjects such as rechargeable batteries and charging infrastructure and corresponds with the aim of building a new distributed system of supplying energy.[32] Among the proposals compiled by the Industrial Technology Subcommittee of the Industrial Structure Council at METI, it espoused a distributed energy society through a "battery revolution," comprising technological innovations that are more than simply an extension of current growth trends, in order to build a first-of-its-kind society that enjoys growth and harmony with the environment.[33] We should also promote the use of capacitors to carry out a part of this battery revolution.

7 Conclusion

The most promising high-energy capacitors are LICs with a hybrid structure combining an EDLC and rechargeable battery. However, nothing has yet been developed to thoroughly demonstrate LICs' attributes. Most prototype cells need to try and further improve their energy density.

If capacitors come into widespread use as automobile power sources—the most demanding conditions in which they would be used—they would have a large ripple effect in other fields such as energy storage, power load equalization and energy regeneration, as well as being an effective way of using energy and helping to further reduce CO_2 emissions. The Japanese people's experience with rolling blackouts due to power shortages in the wake of the Great East Japan Earthquake has made power consumers feel that they need to reduce power consumption during peak hours and to use storage systems that ensure an emergency power supply. The number of storage system applications is increasing with regards to building smart grids as well as managing fluctuating output from renewable energy systems and the balance between supply and demand. Capacitor R&D could gain momentum as one option for these storage systems.

Most companies that make capacitors are in Asia and many are Japanese. There are increasingly more small companies manufacturing and selling capacitors. Lowering costs, increasing energy density and improving reliability will be essential to maintaining the superiority of Japanese companies and popularizing the use of capacitors.

Another issue faced by EDLCs and LICs is their higher system costs compared to rechargeable batteries.[34] However, an assessment of a capacitor's system cost relative to capacitance that includes their long charge/discharge cycle shelf-life shows that they cost significantly less than rechargeable batteries. We also need to consider not using any expensive rare metals in electrodes. We also have to conduct R&D to vastly reduce the costs of cells' constituent materials. In the future, we can expect capacitors to cost less as they become more compact and lightweight, and their use may quickly become more widespread alongside the further popularization of rechargeable batteries. This could result in large reductions in CO_2 emissions.

References

[1] "Survey Concerning the Drafting of Technology Maps for Lithium-Ion Batteries, etc.," NEDO FY 2006 Results Report, (2009)

[2] "Basic Research Needs for Electrical Energy Storage," Report of the Basic Energy Sciences Workshop on Electrical Energy Storage (2007), Office of Basic Energy Sciences, /U.S. Department of Energy: http://science.energy.gov/bes/news-and-resources/reports/basic-research-needs/

[3] Masashi Ishikawa, "Capacitors Opening Up the Energy Society of the Future," KD Neobook, (2007)

[4] Hiroshi Kawamoto and Wakana Tamaki, "Trends in Supply of Lithium Resources and Demand of the Resources for Automobiles," Science & Technology Trends, Dec. 2010, No. 117, p. 17-29

[5] "Next-Generation Vehicle Strategy 2010," Ministry of Economy, Trade and Industry, (Apr. 12, 2010 announcement)

[6] "Vehicle Ownership by Region/Country," Ministry of Land, Infrastructure, Transport and Tourism materials: www.mlit.go.jp/k-toukei/search/pdf/23/23000000x02401.pdf

[7] "Japan's National Greenhouse Gas Emissions (Preliminary Figures)," Ministry of the Environment materials: http://www.env.go.jp/earth/ondanka/ghg/index.html

[8] Hiroshi Kawamoto, "Trends of R&D on Materials for High-Power and Large-Capacity Lithium-Ion Batteries for Vehicles Applications," Science & Technology Trends, Jan. 2010, No.106, p.19-33

[9] Shogo Nishikawa, "Chapter 3: Development of Capacitor Hybrid Trucks and Buses," Development of Large-Capacity Rechargeable Batteries for Automobiles, CMC Publishing, p. 209-221, (2008)

[10] "Chapter 3: Considerations Concerning Regenerative Braking in Electric Vehicles and Improved Functionality": http://dspace.wul.waseda.ac.jp/dspace/bitstream/2065/2929/7/Honbun-4026_05.pdf

[11] Katsuhiko Naoi, "Current State of Capacitors and their Prospects,": http://www4.fed.or.jp/tansaku/yuki/02_naoi.pdf

[12] Wataru Sugimoto, Development of Supercapacitors Using Pseudocapacitance and Double Layers, NEDO FY 2006 Grant Industrial Technology Research Program Research Results Report (Final), (2008)

[13] Michio Okamura, "Electric Double Layer Capacitors and Storage Systems (Ver. 3)," Nikkan Kogyo Shimbun, (2009)

[14] Takashi Chiba, "Developmennt of New Ultimo Lithium-Ion Capacitors," OHM, Aug. 2011, p.34-37

[15] "ESA Technology Comparison": http://www.electricitystorage.org/technology/storage_technologies/technology_comparison

[16] "High-Performance Capcitors Using Single-Layered Carbon Nanotubes (Carbon Nanotube Capacitor Development),." NEDO materials

[17] "Technological Trends and Needs Study Concerning Ionic Fluids," NEDO FY 2007 Study Report (2008)

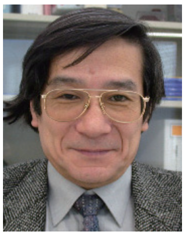
[18] A. Burke, "Ultracapacitor Technologies and Application in Hybrid and Electric Vehicles," Institute of Transportation Studies, University of California, Davis, (2009)

[19] "Redox Capacitors," Waki Group, Department of Energy Sciences, Interdisciplinary Graduate School of Science and Engineering, Tokyo Institute of Technology: http://www.es.titech.ac.jp/waki/research/r_cap-j.html

[20] "Capacitor Batteries and Conductive Polymer Cathodes," Eamex materials: http://www.eamex.co.jp/capa2.

html
[21] Capacitors Utilizing Conductive Polymers: Achieving Both Fast Charge/Discharge and High Capacity, NIKKEI MONOZUKURI November 2011, p.28-29
[22] Atsushi Nishino, "Introduction: Expanding Fields of Application for Next-Generation Electric Double Layer Capacitors," OHM, Aug. 2011, p. 17-23
[23] "MHI Lithium-Ion Capacitor and Lithium-Ion Battery Combined Storage Device Development,." Mitsubishi Heavy Industries PR materials (Feb. 16, 2010): http://www.mitsubishielectric.co.jp/news-data/2010/pdf/0216-d.pdf
[24] "Activated Graphene Makes Superior Supercapacitors for Energy Storage": http://www.bnl.gov/bnlweb/pubaf/pr/PR_display.asp?prID=1275&template=Today
http://capacitors-forum.org/jp/files/CapFmag06.pdf)
[25] Q. Cheng, et al., "Graphene and carbon nanotube composite electrodes for supercapacitors with ultra-high energy density," Physical Chemistry Chemical Physics, DOI:10.1039/c1cp21910c:www.rsc.org/pccp
[26] Katsuhiko Naoi and Kenji Tamamitsu, "New Nano-Hybrid Capacitors": http://www.tuat.ac.jp/~koukai/gakuho/2008/482/news15-2.pdf, (2009)
[27] Katsuhiko Naoi, "Next-Generation Nano-Hybrid Capacitors," Capacitors Forum Newsletter, 2011, Vol. 6, p.15-18: http://capacitors-forum.org/jp/files/CapFmag06.pdf
[28] "Electrochemical Supercapacitor Basic Research, Study on Trends and Joint Research on Application Development," FY 2006 International Joint Research Program, Report on results of International Joint Research Program sending researchers abroad, NEDO, p.151-181, (2007)
[29] Shuhei Monma, "Active Shanghai Capacitor Buses," Capacitors Forum Newsletter, 2001, Vol. 6, p. 15-18: http://capacitors-forum.org/jp/files/CapFmag06.pdf
[30] "International Joint Demonstration and Development Program for Advanced, Integrated and Stable Solar Generation Systems, etc. - Advanced, Integrated and Stable Microgrids (High-Quality Power Supply)," NEDO FY 2007-2009 Results Report, (2010)
[31] "Next-Generation Rechargeable Battery and Storage Devices Technologies" strategic initiative, Japan Science and Technology Agency, Center for Research and Development Strategy, JST-CRDS-FY2011-SP-04, (2011)
[32] "4th Science and Technology Basic Plan": http://www.mext.go.jp/a_menu/kagaku/kihon/main5_a4.htm
[33] "Founding a New National Project System – Proposals by the Research and Development Subcommittee," Ministry of Economy, Trade and Industry: http://www.meti.go.jp/press/2011/08/20110815001/20110815001-2.pdf
[34] "Wasting Capacitors," Nikkei Monozukuri, March 2010, p.61-67

Profiles



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2

U.S. Science and Technology Policy under Tight Budgets: Report on the 2012 AAAS Forum on Science and Technology Policy

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1 Introduction

The American Association for the Advancement of Science (AAAS) holds the AAAS Forum on Science and Technology Policy in Washington, D.C. every year in April or May.[1] The forum, a gathering of the country's science and technology policy insiders, was first held in 1976 as the AAAS R&D Colloquium on Science and Technology Policy. After that the meeting was renamed AAAS Colloquium on Science and Technology Policy, and again renamed current AAAS Forum on Science and Technology Policy. The 2012 meeting was the 37th one.

The 2012 forum was convened for two days on April 26th and 27th. The format began with a keynote address by the Assistant to the President for Science and Technology, followed by an analysis of the president's proposed budget and budget-related discussion. There were then breakout sessions on topics concerning the latest science and technology policies, as well as plenary sessions encompassing a wide range of topics on science and technology's relationship with the economy and society. According to material distributed at the forum, there were over 400 participants from universities, the federal government, non-profit organizations, private companies, overseas organizations and other institutions.

In the city of politics that is Washington, D.C., entities representing various industries organize numerous gatherings to promote their clients' interests and yield benefits for their industries. The initial purpose of the AAAS forum was to contribute to the formation of policy through responsible advocacy by the science and technology community. However, in recent years it has become more of a scene where

Table 1 : Forum Schedule

The schedule for the two-day forum is given below.

(Plenary Sessions)

- Budgetary And Policy Context For R&D in FY 2013
- The William D. Carey Lecture: An Audacity of Imagination
- Coping with Bleak Budgets
- International Trends: A Long-Term View of the Future and Science & Technology's Place In It
- Can the U.S. Innovate Its Way to Jobs and Economic Recovery?

(Breakout Sessions)

- How Voters Actually Think About Issues
- Start-up Tech Firms: Funding and Policy Challenges
- Why - and How - the Federal Budget Process Must Be Reformed
- When People are Research Subjects: Ethical and Policy Questions
- R&D Evaluation During Tight Budget Times
- Regulation and Communication of Risky Science: The Bird-Flu Papers as a Case Study

(Breakfast/Luncheon Speeches)

- Topics: STEM education (Apr. 26 luncheon), the NIH budget (Apr. 27 breakfast) and science and diplomacy (Apr. 27 luncheon)

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the broader science and technology community gathers to establish a shared understanding of budgets and a variety of other policy issues. In addition to the president's proposed budget, the subjects taken up by this year's forum included competitiveness; evaluations; international relations; science, technology, engineering and mathematics (STEM) education; and much more.

Public finances in the United States have come under particularly tough strain in recent years and forecasts concerning the federal budget for the 2013 fiscal year (October 2012 – September 2013) are grim. Accordingly, during forum meetings the members of the academic community were more concerned about asking themselves how they can raise the value of science and technology with limited funding from the federal government, rather than calling for budget increases. This sentiment was shared among the participants.

This paper provides a general overview of the forum by addressing issues such as the Obama administration's science and technology policies, research and education at universities and other subjects, with the current tight budget as a common underlying theme.

2 The Obama Administration's Science and Technology Policies

It is difficult to describe in one word the Obama administration's science and technology policies that began in 2009, but it helps to think of them by dividing them into two broad categories: pre-administration (i.e. Bush administration) policies that were initiated prior to Obama taking office and which are still in effect; and new policies with concepts and purposes that differ from those of the Bush administration's. The former includes a series of measures related to improving competitiveness, such as bolstering basic research.

The defining characteristics of the latter—the new policies began by the Obama administration—can be seen in the "Memorandum on Transparency and Open Government" released the day the president took office. The memo contains three key ideas demonstrating the Obama administration's objectives regarding public administration: "Government should be transparent"; "Government should be participatory"; "Government should be collaborative."[2] Of these, the idea that "government should be participatory" is an effort to improve public administration by sharing government information with the public so they can be involved in policy formation. A number of specific trials to raise policy effectiveness by encouraging citizen participation can be seen within the Obama administration's science and technology policies.

The science and technology policies which the Obama administration has been particularly focused on implementing include: policies that enhance economic effects such as job creation; life science research policies to support the government's healthcare reforms; policies related to the environment and sustainability, including the development of clean energy; and policies related to improving national security. A feature common to these policies is that they include experiments to try and vastly improve government effectiveness by recruiting the active participation of universities, private companies, and even the general public, within a comprehensive policy framework.

For example, while the departments of Commerce, Defense and Energy play a leading role in the Advanced Manufacturing Partnership promoted by the Obama administration, the program also contains parallel initiatives to be executed by universities and industry. In addition, at the same time that the federal government supports basic research and research that bridges the gap between basic research and commercialization, it is also presenting this support as part of its policies to encourage investment (such as tax credit) to promote collaboration between the public and private sectors, as well as its policies on education (including STEM fields). The administration is making clear that stakeholders other than just the federal government should also take appropriate action in response to these policies.

Another characteristic of the Obama administration's science and technology policies is that they are attempting to form initiatives that encompass diverse federal policy measures under a single concept. As an example, the Advanced Manufacturing Partnership is a single initiative that binds together different goals under the concept of "advanced manufacturing": the production capacity of the national security industry; the Materials Genome Initiative (a materials research and development initiative with a name making metaphorical use of the life science term "genome");

Table 2 : The Obama Administration's Science and Technology Policies

What follows is a summary of the Obama administration initiatives mentioned by Mr. Holdren, Assistant to the President for Science and Technology in his keynote address.

○ **Advanced Manufacturing Partnership**[3]

This project announced by President Obama in June, 2011 is intended to improve international competitiveness and create high-skilled manufacturing jobs through a partnership between industry, academia and the federal government. This initiative will invest in emerging technologies such as information technology, biotechnology and nanotechnology.

In his announcement, President Obama said the partnership will: 1) build domestic manufacturing capabilities in critical national security industries, 2) reduce the time to develop and deploy advanced materials, 3) invest in next-generation robotics and 4) develop innovative energy-efficient manufacturing processes. Some of the specific actions the president mentioned, which should involve all stakeholders—universities and private companies—include: new approaches at the Defense Advanced Research Projects Agency (DARPA); practical education programs and industry-academia partnerships at MIT and other higher education institutions; the advanced manufacturing technology consortia developed by the Department of Commerce; advanced software to American small and mid-sized manufacturers made available at no cost by Proctor & Gamble; training for next-generation manufacturing jobs through cooperation between universities and private companies; and Department of Defense investments in domestic manufacturing technology.

The partnership's conceptual background and proposals for specific measures were drafted by the President's Council of Advisors on Science and Technology (PCAST) and the President's Innovation and Technology Advisory Committee (PITAC) in the "Report to the President on Ensuring American Leadership in Advanced Manufacturing." The National Science and Technology Council (NSTC) compiled a concrete implementation plan for the federal government in February 2012 in "A National Strategic Plan for Advanced Manufacturing."

○ **Global Change**

The U.S. government is running the U.S. Global Change Research Program (USGCRP) to deal with the climate change and other global transformations.[4] Started up in 1989, this program to coordinate and integrate research, education and communication as well as to support policymaking, with the intended purpose of building a knowledge base providing information on changes to the climate and the Earth, is now run by 13 federal government departments and agencies. After budget cuts in the previous administration, the Obama administration has been increasing funding for the program. Under the president's proposed budget, the budget for the strategic plan covering FY 2012-2021 is composed of four parts: 1) scientific advances, 2) providing information for policymaking, 3) conducting sustained assessments and 4) communication and education.

○ **Big Data**[5]

The purpose of the Big Data Research and Development Initiative, established in March 2012, is to use the capabilities gained from the growth of information technology in new ways to make scientific discoveries, help the environment and improve research in the life sciences and medicine, education and national security. The initiative has three objectives: 1) Advance state-of-the-art core technologies needed to collect, store, preserve, manage, analyze, and share huge quantities of data; 2) Harness these technologies to accelerate the pace of discovery in science and engineering, strengthen national security, and transform teaching and learning; 3) Expand the workforce needed to develop and use Big Data technologies.

Following the advice of PCAST, this initiative will establish the Senior Steering Group on Big Data in the Executive Office of the President, coordinate efforts throughout the government and execute programs in the NSF, NIH, Department of Defense, Department of Energy and the U.S. Geological Survey.

○ **Bioeconomy[6]**

This is a series of Obama administration efforts to enhance life science research as a driver of innovation and economic growth. The National Bioeconomy Blueprint announced in April 2012 lists the five following strategic imperatives.

1. Support R&D investments that will provide the foundation for the future bioeconomy.
2. Facilitate the transition of bioinventions from research lab to market, including an increased focus on translational and regulatory sciences.
3. Develop and reform regulations to reduce barriers, increase the speed and predictability of regulatory processes, and reduce costs while protecting human and environmental health.
4. Update training programs and align academic institution incentives with student training for national workforce needs.
5. Identify and support opportunities for the development of public-private partnerships and precompetitive collaborations—where competitors pool resources, knowledge, and expertise to learn from successes and failures.

○ **STEM Education (see Figure 4 below)**

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next-generation robotics; higher energy efficiency production processes; and more. In addition to federal R&D support programs such as the many existing projects run by government departments and agencies, these concrete measures include the design of institutions intended to encourage R&D partnerships between universities—as well as between academia and private companies—and the support of small businesses for technological development by large companies

While the federal government has been spending money in this manner and taking measures to promote collaboration outside the scope of government (e.g. between universities and private companies), public finances in the U.S. are in a strenuous situation. In fact, expectations to the initiatives made by the universities and federal government can be understood as another aspect of the very tight fiscal 2013 budget and the difficulties to implement new projects through federal fiscal outlays.

At this year's forum, Assistant to the President for Science and Technology and Director of the White House Office of Science and Technology Policy John P. Holdren reported on the Obama administration's science and technology policies. At the opening of his speech, Holdren, while not touching on any specific figures in the president's Budget, indicated that the Obama administration's idea is not to cut investments in research. He also stated specific initiatives which the administration would promote, including "advanced manufacturing," "global change," "big data," "bioeconomy" and "STEM education" (see Table 2).

After explaining these initiatives, Holdren wrapped up his speech by stating that science and technology are a central part of the Obama administration's overall government policy.

After Holdren's address, he and moderator AAAS CEO Alan Leshner held a discussion that delved deeper into certain initiatives. They also took questions from the audience. There was a question from the floor on the Budget Control Act (addressed in more detail later in this paper) that passed last year and which will generally restrain the president's fiscal

2013 budget proposal. Holdren acknowledged that while science and technology-related budgets have increased more than other items in the discretionary spending budget, they are still in a difficult fiscal situation. The discussion also covered topics such as the significance of the federal government's promotion of international cooperation in science and technology, what the scientific community can do to contribute to public administration, and the federal government's efforts regarding STEM education. During Holdren's interaction with the audience as they asked him these questions, he gave many statements demonstrating the importance the Obama administration places on science and technology and shared the administration's ideas on the initiatives it is promoting, despite the tight restrictions within the president's budget proposal.

3 The Formulation of Science and Technology Policy under Fiscal Austerity

3-1 Forum Participants' Interest in the Federal Budget under the Obama Administration

The federal R&D budget during the preceding administration (Bush Administration) generally focused on defense, while a new development during the latter part of his second term in office with regards to budgeting for basic research was that larger budgets were granted to improve American competitiveness. In contrast, funding for defense-related development has experienced a steady decline during the Obama administration, while being relatively more generous in funding basic research. In addition, the American Recovery and Reinvestment Act of 2009, which was put into law in February 2009 as a response to the financial crisis that began with the collapse of Lehman Brothers, distributed large amounts of research funding: $10.4 billion to the NIH, $3 billion to the NSF, and $1.6 billion to Department of Energy's Office of Science.

Thereafter, as European countries fell into sovereign debt crises and attempted to maintain fiscal restraint, the U.S. took measures such as passing the Budget Control Act. The result was a drastic cut to the amount of discretionary spending in the president's fiscal 2013 budget proposal, with many projects forced to downsize. Yet despite these circumstances the R&D budget rose year-on-year by $2 billion (a 1.4% increase) to $140.8 billion, while funding for basic and applied research rose by 2.7% to $65.3 billion, receiving a generous slice of the budget for discretionary spending.[7] Seen as a possible sign that the Obama administration places importance on science and technology, the forum participants were visibly relieved and no one expressed hope that budgets could expand further.

That being said, the reality is that R&D is experiencing various problems such as cuts of state subsidies to universities and finding the money needed to pay for maintaining the expanded research level brought about by the American Recovery and Reinvestment Act. Furthermore, it was unable to make any predictions on the fiscal 2013 budget. The forum participats' interest turned to how they can improve R&D and yield better results during this time of strained public finances, during which the country as a whole cannot hope for greater support from the federal government.

3-2 The Fiscal 2013 Budget

3-2-1 Overview of the Proposed R&D Budget

AAAS Director of the R&D Budget Analysis Program Matthew Hourihan provided an overview of the proposed fiscal 2013 federal budget during the forum's session on Budgetary and Policy Context for R&D in FY 2013. Hourihan's description of the proposed budget as given in the president's Budget Message (see Table 3) largely followed a booklet handed out to participants entitled "AAAS Report XXXVII: Research and Development FY 2013."[8] He gave particular attention to explaining spending caps and across-the-board cuts, and he mentioned the possibility of a sequestration that would force budget cuts in the future.

Additionally, Lamar Smith, a Member of the U.S. House of Representatives, spoke on a number of legislative processes related to science and technology, though without discussing any particular budget items. More specifically, he explained that inadequate legislative procedures, such as the laws of intellectual property and cyber law, are detrimental. Concerning space, Representative Smith also expressed concern that the only manned spacecraft capable of entering Earth orbit and returning are operated by Russia. He further mentioned the need to spur American children's interest in science through American space activities.

Table 3 : Highlights from the President's Fiscal 2013 Budget Proposal

The American Association for the Advancement of Science (AAAS) is providing information as needed on each fiscal year's R&D budgets based on information from documents released by the Executive Office of the President, federal departments and agencies, as well as from congressional deliberations. Below is a list of proposed budget highlights from "AAAS Report XXXVII, Research & Development FY 2013."*

- The proposed federal R&D portfolio in FY 2013 is $142.2 billion, an increase of 1.2 percent or $1.7 billion over FY 2012 levels.
- Total federal support of research (basic and applied) would increase 2.7 percent to $65.3 billion.
- Federal development spending, however, would decrease 1.7 percent to $74.1 billion.
- The three President's Plan for Science and Innovation agencies (NSF, NIST, DOE's Office of Science) would receive increases, but would fall well short of the doubling pace established in the America COMPETES Act.
- Clean energy is a clear R&D priority in the FY 2013 budget.
- The National Institutes of Health (NIH) would receive a flat R&D budget after a very modest increase last year
- DOD would receive flat funding for basic research, while virtually all other R&D accounts would decline.
- The U.S. Department of Agriculture's (USDA) R&D investment would decrease by 1.5%.

* All dollar amounts appearing in this report are figures compiled from materials provided not only by the Office of Management and Budget (OMB), but also by federal departments and agencies, which may differ somewhat from the figures released by the Executive Office of the President.

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3-2-2 The NIH Budget

American researchers of biology and medicine are extremely interested in the budget for the National Institutes of Health (NIH). NIH Deputy Director for Extramural Research Sally J. Rockey explained that while the NIH's fiscal 2013 budget would remain about the same as the previous year, she said that researchers should be grateful considering the austere times. She also explained that the NIH is considering ways to improve how grants are received in light of the effects of the American Recovery and Reinvestment Act and with researchers' perspectives in mind, as well as ways to improve the processes for distributing grants available as the NIH's actual grant budget declines. Rockey presented specific measures the NIH is considering for improving grant distribution steps such as: shrinking the sum distributed per grant; limiting the number of grants to each principal investigator; setting a limit to the sum each principal investigator can receive; and setting a limit to the salaries of principal investigators.

3-3 Fiscal Austerity and the Budget Process

Other than the aforementioned plenary session, there were two breakout sessions related to the budget: "Why – and How – the Federal Budget Process Must Be Reformed" and "R&D Evaluation During Tight Budget Times."

The U.S. budget process begins when the executive branch drafts a budget proposal in the summer of the year before the year in which the next fiscal year begins in October. As for the science and technology budget, the heads of the Office of Management and Budget (OMB) and the Office of Science and Technology Policy (OSTP) both sign a memorandum listing budget priorities, which are first sent to federal departments and agencies. These then work with the OMB and OSTP to draft budget proposals based on the guidelines in this memorandum. These are then compiled into the president's proposed budget in February of the following year and sent to Congress. Upon receiving the proposal, Congress makes budget resolutions that include revenues, expenditures, the fiscal balance and other information and sets limits.

After the House of Representatives and the Senate go through various revision processes and deliberations concerning the proposed appropriations measures, both houses consult each other to reconcile the measures and send them on to the president, who may sign them into law.

This is the usual budget formulation process, but during deliberations in Congress, it often happens that budget amounts are revised upward and language is added to the budget package due to the interests of members, the situation in their electoral districts and the like. In recent years, however, the government's fiscal problems and other circumstances have made it difficult to conduct smooth budget deliberations, and it has become normal for appropriations to remain unfinished by the start of the fiscal year on October 1. Interim budgets have caused problems such as the risk of a government shutdown, but there are concerns over even greater problems in the fiscal 2013 budget with government finances deteriorating with particular severity. The forum's session on "Why – and How – the Federal Budget Process Must Be Reformed" went beyond the context of the science and technology budget to consider the fundamental problems of the budget system.

Alice M. Rivlin, a Senior Fellow of Economic Studies at the Brookings Institution, pointed out that there are many defects in the legislative process, even with budgets for vital issues such as promoting entrepreneurship and creating innovation. She also pointed out that the cost of healthcare and social security is heavy due to an aging population, among other reasons, while politicians have been unable to find convergence on political issues through deliberations, thus creating a situation conducive to "polarization." In addition, because the process for adopting appropriations has become more complex than before, Rivlin also mentioned that improvements such as a simple and transparent process, or creating a two-year budget cycle with long-term revenue and expenditure forecasts, should be considered, even if they are difficult to implement.

Maya MacGuineas, President of the Committee for a Responsible Federal Budget and Director of the Fiscal Policy Program at the New America Foundation, stated that the "threats" faced by the federal budget require a nonpartisan response with a clear understanding of both the budget deficit and low interest rates in order to have a chance of confronting the "fiscal cliff."

Kenny Kraft, Director of Legislative Affairs – Appropriations at the Boeing Company, expressed hope that the political will to improve procedures relating to issues with both the appropriations process and the budget deficit will materialize. However, he expressed some sympathy for earmarks, a frequent subject of criticism by which members of Congress allocate budgets to certain items during the appropriations process.

This session's question and answer period involved an exchange of ideas covering a wide range of topics beyond the "federal budget process" such as measuring the effects of the budget, reforms to the political system, tax reform, as well as building trust between citizens, the executive branch and Congress.

3-4 The Budget Process and R&D Evaluations

Meanwhile, although the session on "R&D Evaluation During Tight Budget Times" was also about the budget, it covered how the academic community can respond to tight budgets through evaluations, unlike the aforementioned sessions addressing congressional issues.

Kaye Husbands Fealing, Senior Program Officer for the Committee on National Statistics at the National Research Council (NRC), cited an AAAS brief entitled "Potential Impacts of the House Budget on Federal R&D" (April 8, 2012)[9] as she discussed forecasts based on the President's proposed budget and Congress' budget resolutions and explained them within the context of evaluations and other aspects of policy formulation. More specifically, her presentation covered the subject within the contexts of: "Size" (How large should the federal research and development budget be? What is the optimal size of the scientific workforce, particularly in academia? Can research funds be spent in a way to refresh the research enterprise in a sustainable way?); "Options Portfolios" (Where should federal R&D dollars be put – into various fields, technologies, regions; intramural or extramural? What would constitute a "balance" between biological and physical sciences? How many people, possessing what kinds of skills are needed to achieve a robust STI system?); "Implementation" (What do we know about how to make applied research programs work? How and when can such programs be evaluated? What do we know about how to set up a successful demonstration program?);

"Impacts" (What are the employment impacts of federal R&D spending? What impact does federal R&D have on overall economic health, and over what time frame? What impacts are federal R&D programs having on entrepreneurial activities in science and engineering and on innovation?); and "Serendipity" (high-risk research, transformative research, etc.). Fealing also cited a number of evaluation tools and methods (network analysis, visual analytics, scientometric linkages, etc.), cautioning that they should be used accurately.

John L. King of the Resource, Environmental, and Science Policy Branch, Resource and Rural Economics Division, Economic Research Service, U.S. Department of Agriculture discussed two points under the subject of his presentation on "Research Evaluation when Times are Tight": 1) "Use the Process, Trust the Process" (i.e. research programs already have evaluation processes, and new processes should be introduced after a comparison of issues within current processes) and 2) "Make the strongest possible accurate analysis of research programs" (albeit evaluation paradigms do not apply equally to all programs and the best methods for making cuts may not be the best decisions for the research). However, King mentioned, among other things, that investing public funds in research may seem to take quite a long time to bring about benefits and that best practices may not necessarily apply in different fields.

Jerome Pischella, Science and Technology Counsellor for the Embassy of Canada in Washington, D.C. presented Canada's R&D policies. Although Canada enacted deep cuts in the fiscal 2013 budget due to a budget deficit, the innovation and science and technology budgets were spared. He also reported that R&D tax credit has been reduced, while the Canadian government has placed an emphasis on supporting entrepreneurial and business startup programs, as well as strengthening applied research at universities for joint research projects between industry and academia.

The Q&A session for the three aforementioned presentations included specific questions on the implementation of Star Metrics (a joint initiative between the federal government and universities to measure the results of investments in science and technology) and measuring the wide-ranging impact of other scientific research. While each speaker offered his or her own insights, the overall conclusion of these discussions was that policy decisions based on evaluations of scientific research need to be made very carefully and based on sufficient information on all the relevant circumstances, rather than going through simplified procedures.

4 Two Views on Higher Education: Finances and Human Resource Development

4-1 Funding Higher Education

The forum also had a session on budgets in terms of funding higher education entitled "Coping with Bleak Budgets," in which speakers with three different standpoints—a coalition of universities (the Association of American Universities), a university (the University of Oklahoma) and a state-level organization (the Texas Higher Education Coordinating Board)—reported on their responses to the tight federal budget.

According to Department of Education statistics, the United States has approximately 4,500 institutes of higher education, including two-year colleges, but there are not necessarily so many universities that place an emphasis on research. There are 61 members of the Association of American Universities, a group of institutes producing top-level research. According to the Department of Education's "Digest of Education Statistics," there are around 200 universities with research classified as either "very high" or "high." These universities receive a high share of their revenues as federal R&D money, accept capable students from around the world and conduct high-level research. These superior research universities are a symbol of the United States' competitive prowess.[10]

The federal budget has had a major effect on these research universities in recent years through the American Recovery and Reinvestment Act of 2009, which increased the federal government's spending. The act temporarily expanded the amount of research funds distributed through organizations such as the NIH and the NSF, upgraded facilities and equipment at universities and otherwise stimulated research by hiring new personnel. However, the federal budget then returned funding to previous levels, forcing universities that had enlarged the scope of their research to now face the difficult task of continuing the research while the federal government's budget is tight.

Grants given to research universities by state governments have also been subject to cuts. According to data compiled from Department of Education statistics, the total sum obtained by the top 100 universities receiving the grant money from states has been declining since 2008.[11]

The effects of the fiscal problems are not confined to research universities, but are also having a major impact on many other institutes of higher education. Private universities have seen a significant drop in their financial resources since the collapse of Lehman Brothers. State universities have been receiving less state money due to the financial difficulties faced by state governments. As an example, a look at the budget for the University of Oklahoma, as reported during the session, shows that although the university's total operating budget has been rising, state spending dropped slightly in 2012, which when adjusted for inflation was actually a 2.2% drop year-on-year. Even in the nominal budget, the amount of money spent by the state per student dropped, which when adjusted for inflation was a 3.6% reduction.

As for state-level spending on higher education, in Texas, for example, the amount of money for the Higher Education Coordinating Board, which provides assistance to students, had its budget drastically cut for fiscal 2011-2012. In addition, the financial statements of all the state's major universities show that the total sum of state grants is falling.

At the forum, Carrie Wolinetz, Associate Vice President for Federal Relations at the Association of American Universities, compared the budgets allocated to the NIH (mainly for human resources) during the period up until 2003 in which the allocations doubled, and the funds allocated by the American Recovery and Reinvestment Act. Her presentation gave particular attention to the issue of recent research following a temporary expansion of the budgets. She first discussed what is called a "Profzi scheme," which refers to the problem of faculty members who have received grants producing results only in the framework of their fields. Wolinetz also presented data including a breakdown of research funds, the ratios of American and foreign researchers, years until faculty receive tenured positions, the average age of principal investigators and the ages of those receiving regular R01 NIH research grants. She also provided an overview of NIH funding. Then, Wolinetz cited lessons learned from the results of the period during which allocations doubled: the problems of recent years were unavoidable; dealing with finances and the workforce appropriately was difficult; "advocacy fatigue."; and doubts over whether the American Recovery and Reinvestment Act will offer a second chance. She said that while budget increases have positive effects such as raising interest in medical research, there are problems with distributing budgets that focus on inducing economic effects. These problems include the difficulty of properly managing research execution.

Kelvin K. Droegemeier, a professor and Vice President for Research at the University of Oklahoma, gave a report from his own viewpoint. He said that the measures universities can take to deal with a tightening federal budget are: help faculty obtain competitive grants; pursue opportunities to obtain new R&D funding other than just from the NSF or NIH (e.g. the Department of Defense, the Department of Homeland Security, the intelligence community, etc.); provide research opportunities to undergraduate students as well as graduate; build linkages with industry; hope for research assistance from politicians (albeit difficult for individual universities).

Raymond Paredes, the Commissioner of Higher Education from Texas, reported on the problems related to higher education in his state. He explained that although the State of Texas has a diversity of higher education institutes including comprehensive universities, medical universities and community colleges, higher education funding has been on the decline, there are more college applicants and it has been difficult to find ways of dealing with higher tuition, especially for aspiring students from low-income families. However, he said that higher education on all levels needs to innovate, and to do this they need to switch to locally-tailored strategies, collaborate with industry and government (forming workforce pipelines, etc.), and introduce lean processes to spur productivity and streamline costs. He also talked about results-based financing for universities.

4-2 A University's Mission to Develop Human Resources (Especially for STEM Fields)

The White House Office of Science and Technology Policy and other parts of the federal government, as well as science academies and others within the science and technology community, are considering various topics and formulating measures relating to STEM (science, technology, engineering and mathematics) education. This applies to students from

Table 4 : Science, Technology, Engineering and Mathematics (STEM) Education

The most important topic in American science and technology policy as of late has been science, technology, engineering, and math (STEM) education. As mentioned in S. James Gates, Jr.'s presentation (see main body of this paper), the President's Council of Advisors on Science and Technology (PCAST), under the Executive Office of the President, released a report entitled "Prepare and Inspire: K-12 Education in Science, Technology, Engineering, and Math (STEM) for America's Future"[13] in September 2010, followed by "Engage to Excel: Producing One Million Additional College Graduates with Degrees in Science, Technology, Engineering, and Mathematics"[14] in February 2012.

The latter of these two reports was created for the purpose of enriching education at two- and four-year institutes of higher education during the first two years of undergraduate schooling. The authors of the report were aware of this period's importance for life after completing an undergraduate degree program and for training highly skilled workers. The document sets a goal of adding a million people obtaining undergraduate degrees in science, technology, engineering and mathematics over 10 years through steps such as increasing the retention rate until graduation for students studying these subjects.

The actions to achieve the recommendations given by this report are listed below.

Recommendation 1: Catalyze widespread adoption of empirically validated teaching practices

Action 1-1: Establish discipline-focused programs funded by Federal research agencies, academic institutions, disciplinary societies, and foundations to train current and future faculty in evidence-based teaching practices.

Action 1-2: Create a "STEM Institutional Transformation Awards" competitive grants program at NSF.

Action 1-3: Request that the National Academies develop metrics to evaluate STEM education.

Recommendation 2: Advocate and provide support for replacing standard laboratory courses with discovery-based research courses.

Action 2-1: Expand the use of scientific research and engineering design courses in the first two years through an NSF program.

Action 2-2: Expand opportunities for student research and design in faculty research laboratories by reducing restrictions on Federal research funds and redefining a Department of Education program.

Recommendation 3: Launch a national experiment in postsecondary mathematics education to address the mathematics-preparation gap.

Action 3-1: Support a national experiment in mathematics undergraduate education at NSF, the Department of Labor, and the Department of Education.

Recommendation 4: Encourage partnerships among stakeholders to diversify pathways to STEM careers.

Action 4-1: Sponsor at the Department of Education summer STEM learning programs for high school students.

Action 4-2: Encourage pathways from 2- to 4-year institutions through an NSF program and expanded definition of a Department of Labor Program.

Action 4-3: Establish public-private partnerships to support successful STEM programs.

Action 4-4: Improve data provided by the Department of Education and the Bureau of Labor Statistics to STEM students, parents, and the greater community on STEM disciplines and the labor market.

Recommendation 5: Create a Presidential Council on STEM Education with leadership from the academic and business communities to provide strategic leadership for transformative and sustainable change in STEM undergraduate education.

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kindergarten through university, but many forum participants were particularly interested in STEM education for undergraduate students.

As mentioned earlier in this report, it is said that the significance of top-level research is that the graduate schools placing an emphasis on research represent the excellence of American scientific research. Research universities plan for excellence by channeling most research funding to their graduate schools and recruiting exemplary students from around the world. On the other hand, it is also said that they do not necessarily apply this sort of planning to undergraduate education. Since many overseas students skilled in science and engineering fields enroll at American universities after completing undergraduate programs, there are not necessarily so many foreign students in these universities' undergraduate programs. In addition, although circumstances vary by university, research universities tend to treat undergraduate education as separate from their graduate schools' research, while undergraduate students focus on passing their classes to complete their degree programs. Thus, some point out that it is vital for these sorts of research universities to make efforts to enhance their undergraduate programs and to educate a highly skilled U.S. labor force.

Furthermore, higher education institutes other than research universities have less opportunities to win grants. This and other factors make it even more difficult to arouse more interest in research in their undergraduate schools. In addition to ideas appearing in reports by the President's Council of Advisors on Science and Technology (PCAST), the NRC, an organization comprising the country's National Academies, is also considering ways to improve undergraduate education through the introduction of research elements in their programs.[12]

Many forum participants mentioned the importance of STEM education in general. S. James Gates, Jr., a professor at the University of Maryland, College Park and PCAST member, mainly spoke about the White House's efforts.

Professor Gates referred to two PCAST reports (see Table 4) as he presented the views of PCAST and the Obama administration's STEM education-related efforts. He mentioned concrete measures such as offering undergraduate students research opportunities and showing them a variety of pathways, as well as a proposal for establishing a Presidential Council on STEM Education.

5 A Global View of U.S. Science and Technology

Many people, including those in the American science and technology community, are talking about the rise of the BRIC countries and worries over the United States falling behind them. A typical example they give is the Augustine report put out by a national academy. There were multiple sessions at the forum to discuss the United States' competitive position.

During the session entitled "International Trends: A Long-Term View of the Future and Science & Technology's Place in It," James Andrew Lewis, Director and Senior Fellow of the Technology and Public Policy Program at the Center for Strategic and International Studies (CSIS), mainly talked about America's position in terms of economic competitiveness. His comparison of the current situation in the U.S. with Europe and the BRICs covered many aspects: workforce (highly skilled workers, unemployment, immigration, demographics), budget deficits, corruption, policymaking processes, protecting intellectual property, domestic environmental problems and more. The general result of his comparison was that physical indicators show the U.S. has, at the least, adequate capabilities. In addition, Lewis said that the government's defense R&D has been, for the long-term, at the heart of existing industry, and that he expects federal policy, rather than private-sector entrepreneurship, to play more of a role in this sort of R&D.

As described above, Lewis' lecture covered a wide range of topics beyond science and technology, but a number of important questions on science and technology innovation came from the floor. In his responses he said that while American universities remain at as high a level as ever, issues remain such as pipelines of human resources. Lewis also expressed his opinions on issues concerning industrial growth in each field, such as growth in information technology, the lack of clarity over returns on biotechnology investments and the politicization of energy issues.

During the session "Budgetary and Policy Context for R&D in FY 2013," Foreign Policy magazine CEO and Editor-at-Large David Rothkopf gave a lecture entitled "The Global Economic and Political Picture." Today, the world's states, power structures and the like, which have functioned well until now, are facing an assortment of issues including the environment, energy and labor and are in a period of transition that is pushing them to change. Furthermore, Rothkopf said that resolving these issues is made even harder because developed countries are looking inward due to their fiscal problems, while developing countries are doing the same due to domestic social problems.

Concerning educational and labor problems, he also stated that the segment of the American population that has not completed high school is a burden on society and spoke on the importance of technology education and lifelong learning. On the other hand, he also said that the level of higher education leads the world, as it always has.

In addition to issues posed by technology, markets, labor and the like that transcend borders, questions from the floor after Rothkopf's speech also queried problems arising from global austerity.

Regarding science and technology policy from a global standpoint, there was a lecture on the relationship between science and diplomacy. Science and Technology Adviser to the Secretary of State E. William Colglazier's science-related advice to the Department of State, based on his vast personal experience with international science and technology, is to consider whether to formulate policy that helps American science and technology connect somehow to prosperity in other countries while simultaneously benefiting the U.S. in some way. After stating that the research targeted by this support should focus on basic research and pre-competitive research, he did say that this sort of support might go to countries that compete with the U.S., but such countries would also be the market of U.S. products. He added that universities, academic societies and other non-governmental organizations, in addition to the government, would likely play a role in such initiatives. Furthermore, Colglazier stated that a general historical view of the government's international scientific activities reveals that they have had an influence on innovation, education, intellectual property and more. He also mentioned the academic community's importance to these activities.

6 Expectations and Issues Concerning the Social Benefits of Science and Technology

Many forum presenters spoke of expectations that science and technology will be enormously beneficial for society. At the same time, the wide-ranging themes of the forum included deeper inquiries into the relationship science and technology have with society. Such sessions were "Regulation and Communication of Risky Science: The Bird-Flu Papers as a Case Study," which covered papers on the H5N1 bird influenza virus that generated much interest in 2011 and 2012, and "When People are Research Subjects: Ethical and Policy Questions," which was about research ethics.

Meanwhile, there were other sessions that inquired about science and technology's relationship with society in terms of the economic growth brought about by science and technology and what significance and value they have to people.

Jeff Bingaman, a senator from New Mexico and Chairman of the Committee on Energy and Natural Resources, spoke in strong favor of science and technology's benefits in his talk entitled "An Audacity of Imagination." Citing the example of how the exploitation of shale gas has been made feasible despite the difficulty involved, he gave four goals for national energy policy: 1) research leadership, 2) diverse domestic energy resources, 3) promotion of efficient energy usage and 4) reducing adverse environmental impacts. Senator Bingaman said that gaining the consent of the American people is needed to accomplish these goals, after which he expects that science and technology, guided by the proper policies, will lead to social and economic benefits.

Meanwhile the session "Can the U.S. Innovate its Way to Jobs and Economic Recovery?" took up both positive and negative aspects of science and technology's effects on society and the economy, giving equal attention to both with respect to employment. Going beyond the standard question of how much investing in R&D raises employment indicators, the session inquired into whether science and technology truly enrich people as they transform the character of the labor force.

Andrew P. McAfee, Associate Director and Principal Research Scientist at the Center for Digital Business, Sloan School of Management, Massachusetts Institute of Technology, showed data such as inbalanced productivity, jobs and skills. Then, after talking about how technologies like Google Street View and Google Translate have created new possibilities for tasks that humans once did with their own hands, eyes or minds, McAfee said that he expects these sorts of developments to continue.

In contrast to McAfee, Harvard University Professor of Economics Richard B. Freeman expressed a negative view in response to the question of whether technology can enrich people through job creation. Explaining his reasoning, he cited as examples the fact that this enrichment does not affect all people, and that when one considers individual manufacturing sectors, technology does not necessarily create jobs in all of them. Thus, Freeman stated that powerful policy means are needed to resolve these kinds of problems. He added that technological development will display this sort of thinking in disaster response and the proposal and formulation of highly transparent regulatory policies.

Speaking from the perspective of a researcher specializing in communication and culture, Georgetown University Adjunct Professor Michael R. Nelson explained the good and bad technology does for people on five levels: 1) individual, 2) team, 3) company, 4) ecosystem and 5) nation. Concerning the individual level, regardless of any expectations over a cross-field innovation, we still think of things in a field-centric way (academic journals published for each field, funding systems with certain fields as their basis, etc.). Although the team level is thought to be the one with the greatest potential because of Wikis, Skype and other creations made by people with diverse interests and specialties, the teaching at American business schools has not adapted to this situation. As for the company level, companies are in fact a great source of innovation, but there are regulations that currently impede them. Technology produced on the ecosystem level, such as websites created by a few people but used by many, is seen as a model for much innovation and companies are also aware of this merit, but intellectual property rights can impede its growth. On the national level, while there are innovative initiatives such as the America COMPETES Act, many measures are still thought up in old-fashioned ways and the regulatory structure still holds back innovation. Furthermore, Nelson said that if we set comprehensive future goals that develop information technology to scale up the manufacture of a large volume of highly diverse products, while focusing on communities, then we can create work based on sharing, volunteerism and other non-traditional values.

7 Conclusion

The preceding chapters have reported and described in a certain amount of detail the views of the author on the 2012 AAAS Forum. As has already been stated a number of times in this paper, the participants were most interested in how to sustain scientific and technological research under tight budgets. However, the forum also covered many other topics such as economic growth and jobs, university management, undergraduate education and America's international standing. While at first glance these may seem largely unrelated, the author believes that each of these displays a facet of major changes related to science and technology enterprise that are now happening throughout American society. These changes could portend a scenario characterized by a series of negative events in which tight budgets weaken scientific and technological research and hurt employment through slower economic growth, deteriorated university finances reduce the quality of undergraduate education, labor productivity falls and America's international standing drops.

However, the impression the author received from the forum's coverage of these various matters is that participants expressed a desire to create a scenario characterized by a series of positive events in spite of tight budgets: improved education and research at universities, training skilled workers, and using fundamental knowledge to develop industries. What is needed to make this scenario a reality is for all stakeholders to take part and establish the foundation for basic research, training skilled workers and the like, in order to develop manufacturing and other industries for economic growth. Universities, government and companies will all have to address issues together rather than separately. In addition, rather than just relying on recruiting foreign students to exploit their superior skills in their educational programs, universities (research universities in particular) need to devote more effort to educating American citizens, especially in undergraduate programs, to improve Americans' skills and create jobs and economic benefits.

The impression the author received from joining the forum is that it was an opportunity for the participants to share the recognition that in order to achieve this positive scenario, state and local governments, universities, companies and the general public, not just the federal government, all need to make efforts.

References

[1] AAAS Forum on Science & Technology Policy: http://www.aaas.org/spp/rd/forum/

[2] Open Government Initiative: http://www.whitehouse.gov/open

[3] Advanced Manufacturing Partnership: http://www.whitehouse.gov/administration/eop/ostp/pcast/amp

[4] U.S. Global Change Research Program(USGCRP): http://www.globalchange.gov/

[5] Big Data: http://www.whitehouse.gov/sites/default/files/microsites/ostp/big_data_press_release_final_2.pdf

[6] Bioeconomy: http://www.whitehouse.gov/blog/2012/04/26/national-bioeconomy-blueprint-released

[7] Office of Science and Technology Policy R&D Budget: http://www.whitehouse.gov/administration/eop/ostp/rdbudgets

[8] AAAS Report XXXVII:Research and Development FY 2013: http://www.aaas.org/spp/rd/rdreport2013/

[9] AAAS News Brief, Potential Impact of the House Budget of Federal R&D (April 8, 2012): http://www.aaas.org/spp/rd/fy2013/HouseBudgetBrief.shtml

[10] Digest of Education Statistics 2011: http://nces.ed.gov/programs/digest/d11/

[11] Science and Engineering Indicators 2012, Chapter 2 Higher Education in Science and Engineering: http://www.nsf.gov/statistics/seind12/c2/c2h.htm

[12] A recent case that can be cited is “Discipline-Based Education Research: Understanding and Improving Learning in Undergraduate Science and Engineering”: http://www.nap.edu/catalog.php?record_id=13362

[13] Prepare and Inspire: K-12 Science, Technology, Engineering, and Math (STEM) Education for America's Future http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-stem-ed-final.pdf

[14] Engage to Excel: Producing One Million Additional College Graduates with Degrees in Science, Technology, Engineering, and Mathematics: http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-engage-to-excel-final_2-25-12.pdf

Profile

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The subject of Professor Endo's research is science policy in the United States. While at his prior position at the Japan Society for the Promotion of Science, he created the U.S. Science Policy website in 2000 to share policy trends. At the Tokyo Institute of Technology, Endo's research has expanded to include the relationship between science and society, as well as higher education.

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3

United States Government Efforts toward Big Data Research and Development

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1 Introduction

Research and development revolving around "big data" is currently making huge strides in industry, academia and national governments. The term does not quite have an exact definition, but is rather a general way of referring to large quantities of digital data. If we simply think of the extraction of significant information from data as a function which conventional IT techniques excel at, then that is nothing particularly new. However, the amount of data, the speed at which it is being produced and its diversity are all undergoing extraordinary change. In the wake of this change, great advances in how we handle this data—storing and processing—are occurring, and utterly new trends are appearing. New R&D is aiming for creating new value by extracting significant information from a vast amount of data that traditionally was stored but went unused. This shift is the reason why big data is attracting such great interest.

In March 2012, the United States government announced an R&D initiative to utilize big data. The Obama administration's science and technology policies promote five initiatives,[1] and big data is given as one of them. Six government agencies are investing over US$200 million to push forward the big data initiative and try to improve the technologies needed to handle vast amounts of digital data. The most interesting aspect of the initiative is that it sees big data as something that will have as much of an impact on the world as the internet has. In other words, the administration sees big data as something that will have an incredibly huge effect in many areas.

The U.S. is not the only country interested in big data. In Europe, an EU project is trying to find a clear answer for all of Europe regarding issues of growing data in the scientific research community.

In this paper, Chapter 2 presents what big data is, Chapter 3 introduces the R&D initiative launched by the U.S. government, and Chapter 4 explores particularly noteworthy aspects.

Furthermore, discussion about big data in Japan, too, has raised many issues in need of solutions, such as personal information and security problems. One view is that "we will create groundbreaking ideas if we arrange laws and then create circumstances that will not hold back companies' utilization of big data."[2] However, the reason why big data has garnered such worldwide attention is that information has undergone such explosive growth that anyone can access it freely. Accordingly, this paper will leave it to other papers to discuss problems such as security and the like, and instead will mainly address the potential that big data will likely fulfill, primarily conveying positive trends in the U.S.

[NOTE 1] The Japanese government has provided support since 2005 such as: New IT Infrastructure for the Information-explosion Era (info-plosion) by the Ministry of Education, Culture, Sports, Science and Technology (MEXT); the Information Grand Voyage Project by the Ministry of Economy, Trade and Industry (METI); the Development of the Fastest Database Engine for the Era of Very Large Database and Experiment and Evaluation of Strategic Social Services Enabled by the Database Engine under the Funding Program for World-Leading Innovative R&D on Science and Technology (FIRST) program by the Japan Society for the Promotion of Science. Recently, documents from the National Policy Unit, the Council for Science and Technology Policy and MEXT have produced material such as the following:

- The "Strategy for Rebirth of Japan – Opening Frontiers to a `Country of Co-Creation,'"[3] was approved on July 30, 2012 by the National Policy Unit and on July 31 by the Cabinet. Chapter 2 of "IV. Specific Policies for the Rebirth of Japan," "its efforts to establish as a vital policy a solid information and communications infrastructure and thorough use of information and communications technology," states that the government "plans to promote the use of data in the government's possession through: diverse and large amounts of data (big data) that has made collection possible in accordance with advances in information and communications technology; and converging of different fields using information and communications technology."

- Reference material 1-2-2 of the 103rd Plenary Meeting of the Council for Science and Technology Policy held on July 30, 2012, the "FY 2013 – Prioritized Issues and Initiatives of the Priority Policy Package,"[4] listed one prioritized initiative as "promoting the development, standardization and spread of basic technology for the utilization of large-scale information (big data)."
- Document 2 of the 77th meeting of the MEXT Information Science and Technology Committee on July 5, 2012, "Academia's Challenge in the Era of Big Data – Academic Cloud Investigative Commission,"[5] states: "In order to maximize the potential of big data, there is a need, in terms of interdisciplinary collaboration, international collaboration and cultivation of human resources, to pay adequate attention to and promptly get started on those including: R&D in the fields of information, science and technology that will contribute to advancements in data science; R&D relating to big data in system research and the like, to construct an academic cloud environment; and projects relating to the construction of big data utilization models in R&D corporations ."

2 What is Big Data?

2-1 Big Data is...

"Big data" does not quite have an exact definition, but is rather a general way of referring to voluminous digital data. This data is not all collected from one place. It is a variety of data coming from many different areas. Some specific examples are: web info that has experienced enormous growth due to the spread of social networking services (SNS) and the like; large amounts of photos and videos stored on the internet; information from "things" which is information detected by sensors and sent by communication devices; massive amounts of numerical data generated by supercomputers and so forth. This data is becoming so voluminous and complex that conventional techniques cannot manage it.

Most big data is text, images, sensor data and the like. This data is rapidly growing on the internet day by day due to more large pieces of video data being uploaded to websites, in addition to the expanding use of SNSs such as Facebook and Twitter. Furthermore, the "Internet of Things" (IOT) is growing and taking shape. This is the idea of connecting and networking various "things" through the web.

Figure 1 contains excerpts from various materials showing the growth in the volume of data. Here, the vertical axis shows the amount of data on a logarithmic scale. It already shows this amount reaching the zettabyte level, expressing 10^{21}. And for the past few years it has been growing exponentially. Plus, it seems that this momentum will not let up.

2-2 Factors behind the Increasing Scale of Data

Factors we can cite behind the rapid expansion in the scale of data are: the improved ease by which web data can be gathered compared to before; the improved ease by which data can be gathered from devices (data collection from mobile phones, etc.) and things; and advances in storing and processing technologies capable of handling large amounts of data.

To provide an example of gathering web information, creating a database of web information gathered to run a search engine was primarily done manually by people until sometime in the latter half of 1994. However, the global growth of the web demonstrated the limits of this approach. The appearance of programs called web crawlers was a breakthrough. These programs periodically obtain text, images and such from the internet, allowing this data to be automatically collected and organized into a database.[11] Smaller and cheaper communications components and sensors needed to collect data from devices and "things" have made data collection easier. For example, chips have been miniaturized from 10 mm^2 in 2000 to 2-3 mm^2 in 2010, while the average retail price has dropped from around 240 yen in 2000 to 56 yen in 2010. Meanwhile, prices for communication modules that send data collected by sensors and the like continue to fall, while the number of service subscribers has increased.[12]

Recently, many are using Hadoop to process data. Under a situation where enormous dataset is separated and stored in a distributed processing environment comprising numerous computers, Hadoop offers a way to operate in parallel to process the stored data. This open-source software framework is based on Google's MapReduce.[13] Many commercial versions are available to solve various problems through practical application of the software. Meanwhile, the relational database (RDB) has been the optimal compiler technique for over 20 years. At present, both Hadoop and RDBs are in use.

Now, as the collection and accumulation/processing of vast amounts of data is becoming possible, the key is becoming what value we can produce from that data and whether we can connect that to creating new industries and solving social issues. This is the biggest reason for the attention given to big data.

2-3 What People Want from Big Data Analysis

The main characteristics big data has in common are volume (large), speed (real-time) and types (variety).[12]

Regarding large volume, if the size of the data poses a problem, then one could handle it on a smaller scale through sampling, but that ends up giving you a look at only a portion or you may miss seeing something important.[14] Data mining finds conspicuous patterns in a large mass of data and divides that mass into distinctive groups to process and extract information from it. For example, it is easy to think of how this method would help a convenience store find a pattern showing an arrangement of products on its shelves that leads to more sales. Because big data involves such large quantities, it contains common conspicuous patterns along with rare ones. Discovering these rare patterns is one thing businesses want from big data.

Additionally, big data has other potential. Up to now, the study of physics has typically followed a pattern of observation, creating a "formula" from the law inherent to the observed action, which then comes into general usage to recreate physical phenomena. As an example in the case of airplane, a person runs

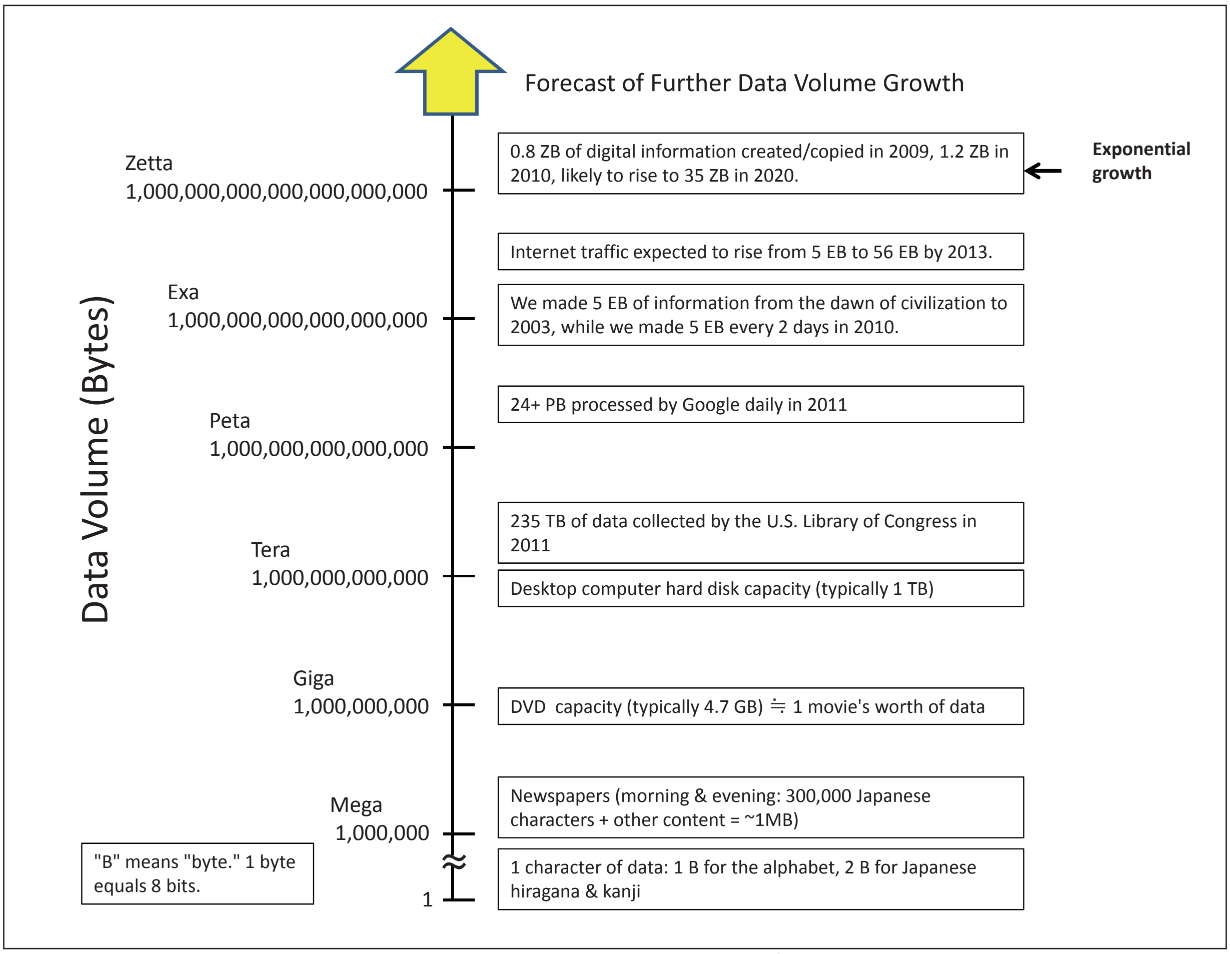

Figure 1 : The Increasing Volume of Data

Source: Compiled by the Science and Technology Foresight Center based on References #6-10.

a simulation employing a formula governing the movement of fluids and analyzes the movement. However, when the movement reaches high speeds, the formula does not work anymore. We can say that big data analysis is a way to distill knowledge with a method other than the accepted, standard “formula.” However, more data is required for this purpose. This is because we need enough data to find a recurring pattern.

As for real-time analysis and diversity, data is input and collected in real time because we can now collect it from more devices and “things” than before. Accordingly, output and feedback via instant processing will become more important. Stream computing[15] is one of the examples that automatically analyzes a constant inflow of data, estimates and leads to rapid decision-making.

Looking at big data from a different perspective, we see that it contains more ambiguity and uncertainty as its quantity increases. During analysis, one must take into account the many uncertain pieces of data.[16] This could become a crucial point for big data analysis in the future.

2-4 Embryonic Cases of Big Data Analysis

This section provides embryonic examples of big data analysis to offer a look at what sort of value they are creating.

2-4-1 Household Health Management

One part of the research conducted by the Information Grand Voyage Project in Japan is an experimental study that uses sensors to research at-home care. According to a report, the project “gets diabetics to measure their blood sugar at home on a continuous basis by using blood sugar-monitoring sensors and acceleration sensors to measure how much they exercise. The research participants are provided with timely messages to encourage certain behavior such as exercise and reducing the amount of food they consume. These messages are called `information medicine.’ When information medicine was administered, it demonstrated that providing timely information that encourages certain behavior is as effective as regular medicine because it successfully suppresses a rise in the participants’ blood sugar level.”[17] This research is focused on individual health management, but it likely has the potential to develop into broader, public health management.

2-4-2 Highly Accurate Translation

Google Translate is an example of how using big data can improve translation accuracy. A free translation service that can instantly translate into 64 languages, it can automatically translate any combination of vocabulary, sentences and webpages from and into any pair of those languages. This is not a conventional method of automated translation employing a prescribed dictionary or grammar rules. To quote an excerpt from Google’s description of the service: “When Google Translate generates a translation, it looks for patterns in hundreds of millions of documents to help decide on the best translation for you. By detecting patterns in documents that have already been translated by human translators, Google Translate can make intelligent guesses as to what an appropriate translation should be. This process of seeking patterns in large amounts of text is called `statistical machine translation.’”[18] This is an example of how having more data produces more significant results.

2-4-3 Road Traffic Information

Big data has been effective at providing road traffic information during normal as well as unusual times. Immediately after the Tohoku Pacific Offshore Earthquake of 2011, GPS data was used to provide road traffic information, demonstrating it is very good at streamlining logistics, such as the transport of relief supplies. Probe information is used for this, which includes information such as the positions and speeds of individual vehicles on the road. ITS Japan uses traffic log data collected anonymously and statistically by four private companies to produce a map showing comprehensive probe traffic information. On the same map, information on road closures based on “the Tohoku Region Restricted Road Access Information and Disaster Information Composite Map” produced by the Geospatial Information Authority of Japan (GSI) was superimposed. This is an example of a public-private partnership providing timely traffic histories and road closure information in a disaster area.[19]

2-4-4 Research on Disaster Response Measures

On June 5, 2012, Japanese MEXT Minister Hirofumi Hirano forged an agreement with Subra Suresh, Director of the National Science Foundation (NSF) in the United States, on the importance of U.S.-

Japan cooperation on disaster research. In essence, the agreement covers research collaboration and assistance through the use of big data in a wide range of fields such as computer science, engineering, social science and earth science. These efforts will be concerned with robustness and resilience against disasters. Specific research fields with promise are given below.[20]

- Advances in applications, such as analysis, modeling and numerical analysis and hazard probability models, by using large amounts of data obtained from disasters.
- Improvements to information technology resilience and responsiveness to allow for real-time data sensing, visualization, analysis and forecasting that is essential to instant decision-making.
- To prepare for times of emergency, integration of diverse knowledge such as inputs from numerous academic disciplines and end users, and large quantities of data from all information sources.

2-4-5 Solutions Development in Industry

Many examples of employing sensor data can be found in industry. Examples include Bridge Monitoring,[21] Agricultural Produce and Management Visualization and Production Process Improvement,[22] services using Context Awareness Technology[23], Energy Management Systems(EMS) and the like.

Other examples include “recommendations” for products and services employing purchase log information from websites and SNS information, as well as services providing information linked directly to GPS positional information and sales support.

It is assumed that these products and services will grow and change more and more as big data technology improves, and this should take solutions development in industry another step further.

3 U.S. Government Big Data Initiative

The Obama administration’s science and technology policies promote five initiatives,[1] and big data is given as one of them. This chapter introduces the Big Data initiative launched by the U.S. government.

3-1 The OSTP Big Data Initiative

The Office of Science and Technology Policy (OSTP) announced an R&D initiative to utilize big data,[24] for which U.S. federal agencies are making new investments of more than US$200illion. The goals are to help solve pressing national issues and increase capabilities for drawing insights and knowledge from large and complex sets of digital data. First, six agencies (the NSF, NIH, DoD, DARPA, DOE and USGS) will invest in research to improve tools and technologies for handling big data. Assistant to the President and Director of the White House OSTP Dr. John P. Holdren said, “In the same way that past Federal investments in information-technology R&D led to dramatic advances in supercomputing and the creation of the Internet, the initiative we are launching today promises to transform our ability to use Big Data for scientific discovery, environmental and biomedical research, education, and national security.”

The following R&D objectives have been cited by this initiative:

- Advance state-of-the-art core technologies needed to collect, store, preserve, manage, analyze, and share huge quantities of data.
- Harness these technologies to accelerate the pace of discovery in science and engineering, strengthen our national security, and transform teaching and learning.
- Expand the workforce needed to develop and use Big Data technologies.

This initiative was described as a response to advice from the President's Council of Advisors on Science and Technology in 2011, which concluded that “the Federal Government is under-investing in technologies related to Big Data.”[24]

U.S. government agencies have already initiated various efforts related to big data. On March 29, 2012, on the same day it announced the R&D initiative, the OSTP released a “Fact Sheet”[25] on big data. With this document, the OSTP cited many examples to highlight ongoing government programs that are addressing the challenges of the "big data revolution" to advance agency missions and innovation through scientific discovery. Table 1 shows the agencies and number of programs listed in the Fact Sheet.

The following subsections present six agencies implementing the Big Data Initiative. (Some are also listed in the above-mentioned Fact Sheet.)

Table 1 : Agencies and Number of Programs Listed in the Fact Sheet

Agency	Number of Programs
Department of Defense (DoD)	10
Department of Homeland Security (DHS)	1
Department of Energy (DoE)	12
Department of Veterans Affairs (VA)	9
Health and Human Services (HHS)	5
Food and Drug Administration (FDA)	1
National Archives and Records Administration (NARA)	1
National Aeronautics and Space Administration (NASA)	7
National Institutes of Health (NIH)	23
National Science Foundation (NSF)	16
National Security Agency (NSA)	3
United States Geological Survey (USGS)	1

Source: Compiled by the Science and Technology Foresight Center based on Reference #25.

3-1-1 NSF & NIH Joint Support

The National Science Foundation (NSF) and the National Institutes of Health (NIH) are conducting R&D on core technologies to advance big data science and engineering. To be specific, they released a joint "big data" solicitation for NSF and NIH support to advance the core scientific and technological means of managing, analyzing, visualizing, and extracting useful information from large and diverse datasets. The purpose is to speed up scientific discoveries and create new fields of inquiry that cannot be explored by other means. The NIH is taking a particular interest in imaging, molecular, cellular, electrophysiological, chemical, behavioral, epidemiological, clinical, and other data sets related to health and disease.

3-1-2 NSF

In addition to the NSF's continual focus on basic research through the aforementioned big data solicitation, the agency has declared a comprehensive, long-term strategy that includes new methods to derive knowledge from data, and to construct new infrastructure to manage, curate (see NOTE 2 below) and serve data to communities, as well as new approaches for education and training. Specific aspects of the strategy are given below.

●Encouraging research universities to develop interdisciplinary graduate programs to prepare the next generation of data scientists and engineers.

●Funding a $10 million Expeditions in Computing project based at the University of California, Berkeley, that will integrate three powerful approaches for turning data into information - machine learning, cloud computing, and crowd sourcing.

●Providing the first round of grants to support "EarthCube" – a system that will allow geoscientists to access, analyze and share information about our planet.

●Issuing a $2 million award for a research training group to support training for undergraduates to use graphical and visualization techniques for complex data.

●Providing $1.4 million in support for a focused research group of statisticians and biologists to

[NOTE 2] The meaning of "curate" and "curation"

The terms "curate" and "curation" hold significant meaning in terms of creating value from big data. In this case, curation is gathering information from the internet or classifying gathered data, connecting pieces of data to give it new value, and then sharing it. Japanese dictionaries define the English word "curation" as "collecting information and such, organizing it, adding value from new perspectives, and sharing that information with others." (from http://kotobank.jp/word/%E3%82%AD%E3%83%A5%E3%83%AC%E3%83%BC%E3%82%B7%E3%83%A7%E3%83%B3)
(from http://www.nttpc.co.jp/yougo/%E3%82%AD%E3%83%A5%E3%83%AC%E3%83%BC%E3%83%88.html)

determine protein structures and biological pathways.

- Convening researchers across disciplines to determine how Big Data can transform teaching and learning.

NSF Director Subra Suresh has said, "American scientists must rise to the challenges and seize the opportunities afforded by this new, data-driven revolution. The work we do today will lay the groundwork for new enterprises and fortify the foundations for U.S. competitiveness for decades to come."

NSF also states "in the near term, NSF will provide opportunities and platforms for science research projects to develop the appropriate mechanisms, policies and governance structures to make data available within different research communities".[26]

3-1-3 DoD

The Department of Defense (DoD) is starting up programs under the Data to Decisions initiative, and is "placing a big bet on big data." It is investing approximately US$250 million annually (allotting US$60 million to new research projects) across the Military Departments in a series of programs. Programs are listed below.

- Harness and utilize massive data in new ways and bring together sensing, perception and decision support to make truly autonomous systems that can maneuver and make decisions on their own.
- Improve situational awareness to help warfighters and analysts and provide increased support to operations. The Department is seeking a 100-fold increase in the ability of analysts to extract information from texts in any language, and a similar increase in the number of objects, activities, and events that an analyst can observe.

To accelerate innovation in Big Data that meets these and other requirements, DoD will announce a series of open prize competitions over the next several months.

3-1-4 DARPA

The Defense Advanced Research Projects Agency (DARPA) develops computational techniques and software tools to analyze large quantities of data comprising both semi-structured data (e.g. tabular, relational, categorical, meta-data, etc.) and unstructured data (e.g. text documents, message traffic, etc.). DARPA is launching the XDATA Program, with plans to invest roughly US$25 million a year over a four-year period. The main research subjects are:

- Development of scalable algorithms that process imperfect data within distributed data stores.
- Creation of effective interaction tools between humans and computers to facilitate rapidly customizable visual reasoning for diverse missions.

The XDATA Program will support an open source software kit to allow for flexible software development.

The following is a slightly more detailed introduction to the XDATA Program, which is slated to receive a heavy dose of investment.[27]

Since technology development will also be guided by end-users with operational support expertise, DARPA will engage elements of the DoD and other agencies to develop use cases and operational concepts. This will result in a "development-in-process" software development model, where agile libraries, APIs, and code instances will be refined based on user feedback. User groups of selected personnel from the DoD and other agencies will be maintained throughout the life of the program.

The XDATA Program is placing importance on developing fast, scalable and efficient methods in order to process and visualize data. And it is not only support ingestion and transformation but also enable fast search and analysis.

The program comprises four "Technical Areas":

TA1: Scalable analytics and data processing technology
TA2: Visual user interface technology
TA3: Research software integration
TA4: Evaluation

The program intends to maintain a technology integration facility in the greater Washington, DC, area to facilitate agile and collaborative software development, integration, and testing/evaluation. User interaction, use-case development, and integration, test, and evaluation are intended to take place at this facility.

3-1-5 NIH

In addition to the aforementioned joint development of core technologies with the NSF, the National Institutes of Health (NIH) is announcing that the world's largest dataset on human genetic variation produced by the international 1000 Genomes project (see NOTE 3 and Reference #28) has been made possible by cloud computing (hereafter referred to as the "cloud").[28] In collaboration with Amazon.com, Inc. (hereafter referred to as "Amazon"), the datasets are already available to the public via Amazon Web Services' (AWS) cloud. The size of this data is 200 terabytes, enough to fill 16 million file cabinets worth of documents or more than 30,000 standard DVDs. The 1000 Genomes project's current data set is a prime example of big data. Because the quantity will further expand, there are still few researchers at present with the computational capabilities to optimally utilize this data. AWS is hosting the project's data, allowing researchers free and public access to the datasets. They only have to pay for the computational services they themselves use.

3-1-6 DoE

The Department of Energy (DoE) is using part of a five-year funding allotment of US$25 million to establish the Scalable Data Management, Analysis and Visualization Institute (SDAV) through the Scientific Discovery Through Advanced Computing (SciDAC) program.[29] At SDAV, the Lawrence Berkeley National Laboratory is leading five other national laboratories, along with seven universities, to combine the partners' expertise. The goal is to develop new tools to help scientists manage and visualize data on the Department's supercomputers, which will further streamline the processes that lead to discoveries made by scientists using the Department's research facilities. The need for these new tools has grown as the simulations running on the Department's supercomputers have increased in size and complexity.

According to the reference[29], reasons for establishing SDAV are described as follows.

As the scale of computation has exploded, the data produced by these simulations has increased in size, complexity, and richness by orders of magnitude, and this trend will continue. However, users of scientific computing systems are faced with the daunting task of managing and analyzing their datasets for knowledge discovery, frequently using antiquated tools more appropriate for the teraflop era. While new techniques and tools are available that address these challenges, often application scientists are not aware of these tools, aren't familiar with the tools' use, or the tools are not installed at the appropriate facilities.

In order to respond to these issues, SDAV is developing and preparing technical solutions in the three fields of data management, analysis and visualization, with the goal of using these solutions to help scientists in all disciplines.

3-1-7 USGS

The U.S. Geological Survey (USGS) is looking at big data for Earth system science. The agency is already issuing grants through the John Wesley Powell Center for Analysis and Synthesis. The Center catalyzes innovative thinking in Earth system science by providing scientists a place and time for in-depth analysis, state-of-the-art computing capabilities, and collaborative tools invaluable for making sense of huge data sets. Big data projects in Earth system science will improve understanding of issues such as species response to climate change, earthquake recurrence rates, and the next generation of ecological indicators.

3-2 Establishment of the BD SSG

Up to now the U.S. government has conducted R&D on information and communications technology with the Networking and Information Technology Research and Development (NITRD) program formulated by the National Science and Technology Council (NSTC). Fifteen government agencies are involved in the NITRD program. It contains seven individual research fields called Program Component Areas (PCAs) and five Senior Steering Groups (SSGs) that handle priority issues requiring interagency collaboration. Individual programs run by each agency are done in collaboration with other agencies. The "Bluebook" ("Supplement to the President's Budget") relating to NITRD program plans and budgets is published annually.

The overview sates the followings.

The Big Data Senior Steering Group (BD SSG) was established in early 2011,[30] making big data an area for interagency collaboration.

The BD SSG has been formed to identify current big data research and development activities across the Federal government, offer opportunities for coordination, and begin to identify what the goal of a national initiative in this area would look like. The

[NOTE 3] The 1000 Genomes project is a public-private consortium formed in 2008 to create a detailed map of genome variation between more than 2,600 people from 26 populations from around the world.

group was established due to increasing concerns over data preservation, access, dissemination, and usability as data volumes grow exponentially. Research into areas such as automated analysis techniques, data mining, machine learning, privacy, and database interoperability are underway at many agencies. Studying this will help identify how big data can enable science in new ways and at new levels.

According to records, BD SSG was formed to identify programs across the Federal government and bring together experts to help define a potential national initiative in this area. BD SSG has been asked to identify current technology projects as well as educational offerings, competitions, and funding mechanisms that take advantage of innovation in the private sector. In this function, records also show that the BD SSG collects information on current activities across the Federal Government, creates a high-level vision of the goals of a potential national initiative, develops the appropriate documents and descriptions to aid discussion within the government, and where appropriate, the private sector, and develops implementation strategies that leverage current investments and resources.

4 Noteworthy Aspects of the U.S. Government Big Data Initiative

This chapter cites particularly noteworthy aspects of the U.S. government's big data initiative described

Tabele 2 : Key Points and Research Areas of U.S. Gov't Agency Big Data Research Support

Agency	Technological Development	Education & Training	Data Sharing	Policy Incentives (Provision of facilities, recruiting researchers, etc.)
NSF & NIH	– Core technologies to manage, analyze, visualize and extract information from big data			
NSF	– Integrate machine learning, cloud computing and crowd sourcing, and extraction of information from data ($10 mil)	Encourage research universities for development of graduate programs to train data scientists and engineers Support a focused research group of statisticians and biologists to determine protein structures and biological pathways ($1.4 mil) Support acquisition of visualization techniques, subsidies to teach undergrad students how to handle big data ($2 mil)	"EarthCube": helps geoscientists access, analyze and share data on the Earth	Convene researchers across disciplines to determine how Big Data can transform teaching and learning
DoD	– Harness and utilize massive data in new ways and bring together sensing, perception and decision support to make truly autonomous systems –Improve situational awareness to help warfighters and analysts and provide increased support to operations (100x capability upgrade to extract info from text in any language, and a similar increase in the number of objects, activities, and events that an analyst can observe) ($250 mil, of which $60 mil for new projects)			Open contests over several months with prizes for winners to accelerate innovation with big data
DARPA	Development of software tools and computational methods to analyze big data (XDATA Program) – Development of scalable algorithms that process imperfect data within distributed data stores – Creation of effective interaction tools between humans and computers to facilitate rapidly customizable visual reasoning for diverse missions – Development of flexible software by offering an open source software kit ($25 mil annually over 4 years)			Maintain a technology integration facility to facilitate agile and collaborative software development, integration, and testing/evaluation in XDATA Program
NIH			Free access to human genome information on Amazon's AWS cloud	
DoE	– Establishment of the SDAV; development and growth of supercomputer data management, analysis and visualization tools ($25 mil over 5 years)			
USGS				Provision of a place, time and computational power for analysis of the Earth, the environment, the climate, etc.

Source: Edited by the Science and Technology Foresight Center based on Reference #24.

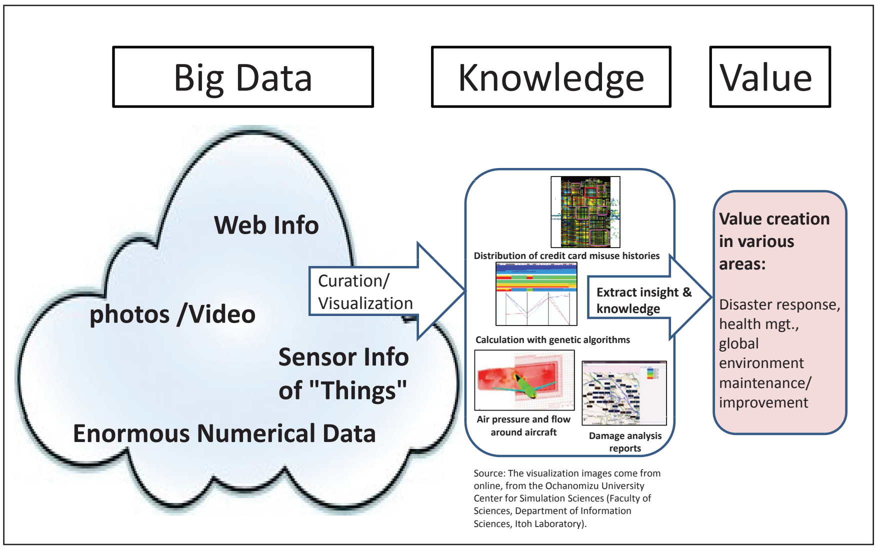

Figure 2 : Creating Value from Big Data

Source: Compiled by the Science and Technology Foresight Center.

in Chapter 3. Table 2 shows agencies discussed in Chapter 3 and the research support they are providing to each research subject area.

4-1 How to Look at Big Data

Assistant to the President and Director of the White House OSTP Dr. John P. Holdren believes big data may have as great an impact on the world as the internet. In other words, he sees it as having a very large influence on science and technology in general as well as society. "Academia's Challenge in the Era of Big Data – Academic Cloud Investigative Commission,"[5] a document released by MEXT, describes the U.S. view on big data as below.

"The concept behind the United States' Big Data Initiative is to provide powerful solutions to the important technological problems of the future. The U.S. government sees big data is the same importance as both supercomputers and the internet. It believes that improving the core technology behind massive data will contribute to security, educational reforms and training, and the NSF sees that technical issues to confront are graduate courses to train data scientists, machine learning, cloud computing and crowd-sourcing."

4-2 Focus on Visualization Technology in Technical Development

The contents related to visualization are seen most common among the table 2. In short, comprehensive solutions to numerous problems are needed to create value from big data, among them, visualization may be considered as the most important technological aspect. It also believes that there is an intimate relationship between analysis and visualization and that processing which does not relate to visualization will have trouble creating value. It is important to visualize and extract knowledge, then link that to action that creates value. It may be said that this is source of thinking (see Figure 2).

Visualization is incorporated into the joint research by the NSF and NIH, as well as by DARPA, the DoE, indicating that these agencies recognize its importance.

4-3 Relationship with Cloud Computing

A previous report in the June 2010 issue of Science and Technology Trends has more detail on "Cloud Computing," but the spread of the cloud is one factor behind big data's advance. For example, NIH projects use Amazon's cloud services. The primary significance of access to the cloud is that it is easy and low cost burden for researchers to use. One description of the NIH's 1000 Genomes project is: "AWS is hosting the 1000 Genomes project as a publically available dataset for free, and researchers will pay for the computing services that they use."

It goes without saying that big data involves huge quantities of data. In order to process it, a large quantity of disks and computers are needed. And if data is not input or output in parallel, then too much time is taken. Input or output time is shortened by providing multiple disks in multiple computers which can be accessed in parallel. Cloud is an essential element for big data as a means of providing a large quantity of both disks and computers.

4-4 Considerations to Human Resource Development

Human resource development is vital because mathematical, statistical and legal knowledge, and business management expertise are needed to find value within big data. The NSF's description of its programs include preparation such as development of graduate programs to cultivate data scientists and engineers, support for research groups comprising statisticians and biologists, and grants for research to cultivate undergraduate students by helping them to acquire visualization techniques.

Although not limited to big data, many Western projects embrace this sort of education. As examples from Europe, in FP7 projects and the PRACE project[31] that provide high-end supercomputers to researchers throughout Europe, specialists provide the training (or education) and public relations.

4-5 Active Participation by Industry and Academia

OSTP Deputy Director for Policy Tom Kalil is calling for private companies and universities to actively participate in big data efforts. He wrote, "We also want to challenge industry, research universities, and non-profits to join with the Administration to make the most of the opportunities created by Big Data. Clearly, the government can't do this on its own. We need what the President calls an "all hands on deck" effort."[32] A real-world example of this happening is Amazon's collaboration with the NIH's 1000 Genome project.

One problem in R&D is that when a project comes to a close, research is discontinued and the chances of the results being put to use for the public decrease. We need ways to continue and expand R&D so that society can utilize it.

4-6 Encouraging Data Sharing

The Big Data Initiative is encouraging the sharing of data. For example, at the NIH, open access to the datasets produced by the 1000 Genomes project is available through the AWS cloud. In addition, at the NSF, the EarthCube which assists any scientist in accessing, analyzing and sharing data on the Earth is supported.

The United States has a website, Data.gov,[33] that launched on May 21, 2009 and allows retrieval of information and data held by government agencies. Although the purpose is not data sharing for the researcher community, the goal of Data.gov is to provide the public with free and easy access to high value, machine readable data sets generated and hosted by the federal government. It will enable the public to easily find, access, understand and use data that are generated by the Federal government.

And in Europe, the purpose of EUDAT (European Data Infrastructure)[34], an EU project, is to provide Europe with solutions to problems arising from the growth of data in the scientific research community. Thus, both the U.S. and Europe are aiming to conduct research efficiently by sharing data, and the direction both are taking is to build the infrastructure and tools to make this happen.

4-7 Other Noteworthy Aspects

The DoD wants to improve situational awareness to help warfighters and analysts and provide increased support to operations. As part of this, the department wants to achieve a hundredfold increase in capabilities to extract information from text in any language. Although this is a military application, in the future it could also expand to the public. Thus, this could be very attention-worthy R&D that may conceivably lead to dramatic changes.

Additionally, DARPA is working on very interesting projects involving scalable algorithms to process imperfect data within distributed data stores as well as interaction tools between humans and computers to speed up customization.

5 Conclusion

"Big data" does not quite have an exact definition, but is rather a general way of referring to large quantities of digital data. It is so large that it cannot be managed with existing techniques, and it is complex data. Work is underway to extract value from it.

The United States government's Big Data Initiative covered by this paper is said to also include projects that have been run since prior to the initiative. To be frank, it has a feel of a hodgepodge of many different projects. However, it resembles the NITRD program in that the Big Data Initiative seems determined to enlist the cooperation of many agencies under the umbrella of "big data." The initiative is one example of the Obama administration's science and technology policies, which include "experiments to try and vastly improve government effectiveness by recruiting the active participation of universities, private companies, and even the general public, within a comprehensive policy framework" and is trying to "form initiatives that encompass diverse federal policy measures under a single concept."[1]

The most interesting of the initiative's R&D efforts is "How to Look at Big Data." The U.S. government sees big data as science and technology that may contribute to the creation of a new paradigm and will have a very major impact in many realms, as the internet did. Noteworthy aspects of the initiative include the "Focus on Visualization Technology," the "Relationship with Cloud Computing," "Considerations to Human Resource Development," "Active Participation by Industry and Academia" and "Encouraging Data Sharing." We can also see that the U.S. is giving thought to policies such as those encouraging the provision of facilities and computing power conducive to collaborative work. Since the results produced by the initiative's R&D may become widely used and penetrate to society in a few years or decades and lead to major innovations, future developments will be worthy of our attention.

Considering the growth of R&D into big data around the world and the difficulty of the challenges involved, global collaboration will be vital for future R&D. Another sign of big data's promise came in June of 2012, when Japan's MEXT minister forged an agreement with the American director of the NSF on the importance of cooperation in disaster-related research. For example, the NSF will "collaborate on big data and disaster research" with MEXT for the Global Research on Applying IT to Support Effective Disaster Management Award (GRAIT-DM) granted by the Science Across Virtual Institutes (SAVI) program.[35] Japan should also engage in this sort of global collaborative research in order to encourage big data research, and produce exceptional value.

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References

[1] "U.S. Science and Technology Policy under Tight Budgets: Report on the 2012 AAAS Forum on Science and Technology Policy," Science and Technology Trends, July/August 2012
[2] http://www.mizuho-ir.co.jp/publication/navis/017/pdf/navis017_07.pdf
[3] http://www.npu.go.jp/policy/pdf/20120731/20120731.pdf
[4] http://www8.cao.go.jp/cstp/siryo/haihu103/sanko2.pdf
[5] "Academia's Challenge in the Era of Big Data – Academic Cloud Investigative Commission," 77th meeting of the Information Science and Technology Committee, Document 2
[6] http://gigaom.files.wordpress.com/2010/05/2010-digital-universe-iview_5-4-10.pdf
[7] http://idcdocserv.com/1142
[8] http://www.i-cio.com/features/august-2010/eric-schmidt-exabytes-of-data
[9] A Vision for Exascale (Mark Seager, Intel) 2012.6 ISC12
[10] Big data: The next frontier for innovation, competition, and productivity, McKinsey Global Institute 2011.5
[11] http://ja.wikipedia.org/wiki/%E3%82%AF%E3%83%AD%E3%83%BC%E3%83%A9
[12] "How to Use Big Data," Information and Communications Council, ICT Basic Strategy Board, Ad Hoc Group on Utilization of Big Data, May 17, 2012
[13] http://research.google.com/archive/mapreduce.html
[14] Takeaki Uno, "Theoretical Computation Approaches for High-Speed Big Data Processing," Information Processing Society of Japan 2012 Seminar, Big Data and Smart Companies, July 25, 2012
[15] http://www-06.ibm.com/ibm/jp/provision/no65/pdf/65_article2.pdf
[16] http://www.slideshare.net/IBMDK/global-technology-outlook-2012-booklet

[17] Masuru Kitsuregawa, “Fourth Generation of Media will Create the Big Data Age,” (ProVISION, Winter 2012, No.72, p13-14)
[18] http://translate.google.com/about/intl/ja_ALL/
[19] http://www.its-jp.org/saigai/
[20] http://www8.cao.go.jp/cstp/tyousakai/innovation/ict/4kai/siryo4.pdf
[21] Yasushi Sakurai, “Mining Technologies for Data Streams and their Application,” Information Processing Society of Japan 2012 Seminar, Big Data and Smart Companies, July 25, 2012
[22] http://jpn.nec.com/press/201207/20120713_03.html
[23] “Trends and Issues in Research on Context Awareness Technologies for a Ubiquitous Network Society,” Science and Technology Trends, August 2007
[24] http://www.whitehouse.gov/sites/default/files/microsites/ostp/big_data_press_release_final_2.pdf
[25] http://www.whitehouse.gov/sites/default/files/microsites/ostp/big_data_fact_sheet_final.pdf
[26] http://www.nsf.gov/news/news_summ.jsp?cntn_id=123607
[27] Broad Agency Announcement XDATA DARPA-BAA-12-38
[28] http://www.1000genomes.org
[29] http://sdav-scidac.org/report.html
[30] http://www.nitrd.gov/Index.aspx
[31] http://www.prace-project.eu/?lang=en
[32] http://www.whitehouse.gov/blog/2012/03/29/big-data-big-deal
[33] http://www.data.gov/
[34] http://www.eudat.eu/
[35] http://www.nsf.gov/news/special_reports/savi/awards.jsp#grait-dm

Profiles

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4

Design Thinking Education at Universities and Graduate Schools

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1 Introduction

We have come to understand very well from various past examples that the products of research in science and technology—research papers, patents and the like—do not on their own bring about outcomes in economies and societies.[1] New ways of thinking and new approaches are needed in order to link more of the science and technology-related results we create with social and economic results.

The 4th Science and Technology Basic Plan[2] sets its sights on generating innovation in society by shifting from the conventional focus on individual fields to a concentration on problem-solving and task accomplishment, thus marking a major shift in direction. The Basic Plan employs the word "innovation" in the phrase "implementation of innovation through science and technology" to link the products of science and technology with real-world society and to solve social issues.

The primary fundamental idea concerning action to generate innovation is that humans are the key to bringing it about. Educating innovators (also called "frontier talent" and the like) and utilizing them effectively is essential to innovative action by an organization or society.[3,4] Furthermore, industry and society as a whole are calling on universities, graduate schools and other institutes of higher education to teach and turn out these sorts of graduates.

Education has always been important in every aspect of science and technology. Everyone has agreed that education is vital for scientific and technological advancements. This journal, Science and Technology Trends, has frequently taken up the subject of education in various fields.[5] However, these publications have thus far only discussed the topics within the constraints of certain fields and or industries. Their arguments have not gone beyond the paradigm of field-specific discussion to address educational methods that aim to generate innovation which spawns new fields and new industries, rather than adopting the existing field-specific educational practices[NOTE 1]

General innovation theory observes that creating knowledge by involving multiple perspectives and multiple fields could produce completely different results from those created within conventional specific fields or single industries. However, taking this approach requires a team of individuals other than those with only one area of advanced expertise.[13]Yet it is quite difficult to form teams of individuals with such qualities via the traditional approach by which we have educated people within certain field, as symbolized by the traditional university structure of undergraduate and graduate school departments.

Thus the "design thinking" approach to education[11, 18] has garnered attention as a way to educate people who can find solutions to problems straddling multiple fields, as well as discover new problems and assign further tasks to carry out. Numerous universities and graduate schools in countries around the world have begun teaching design thinking.

This paper addresses the questions of what ideas design thinking education is based upon, and how it is actually being conducted at universities and graduate schools, by describing typical examples outside Japan. The list of universities and graduate schools that have begun teaching design thinking.is also included.

[NOTE 1] In all fields of study, even older ones, the knowledge and experience outside one's field is effective for generating innovation. For example, for truly advanced ICT experts at the top of the field, in an age when information systems act as the nervous system of society and industry and when IT and management are converging, we need people with T-type and π-type personalities to produce innovation.

2 The Design Thinking Approach

2-1 What is Design Thinking?

The reason that the design thinking approach is garnering attention is that it has shown that it can find, propose and implement appropriate solutions, even in entirely new fields. For example, there have been cases in which design thinking has offered numerous solutions in areas such as new business ideas for starting up social enterprises or solving problems in developing countries.[6] And when developing a product in a company, it is extremely difficult for a developer to fathom society's latent needs, no matter how much thought is given to it at the drawing board. Meanwhile if we look at the world at large, we see that smart phone applications and social network services like Facebook and twitter show latent needs that had existed in society, but they have also created new industries that had not existed before. Design thinking education, as explained later in the paper, has a good record of effective outcome in such areas with remarkable changes, and. is recognized as an effective development method, thus becoming more entrenched nowadays. This approach employs a streamlined prototyping process that tests the value of services and applications in the real world and understands the true value through feedback loops.

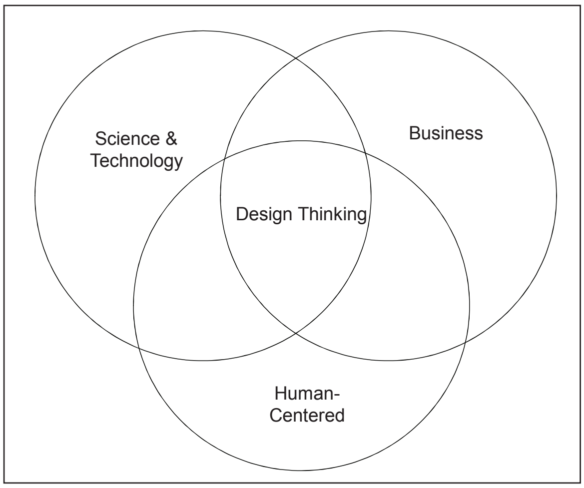

Figure 1 : Three Elements of Design Thinking
Compiled by the Science and Technology Foresight Center

As shown in Figure 1, design thinking, which proceeds towards implementation from concept on through to ideation, is a design approach that combines a trio of human-centered[NOTE 2], scientific/technical and business elements. The names of the three elements do not contain the word "design" and include one that is "human-centered" to emphasize that the approach is not limited to design in the narrow sense of the word (e.g. industrial design or design technology). If the act of engaging in design thinking is not exclusive to a designer in the narrow sense of the word, then it is in fact not just a recent development.[NOTE 3]

2-2 The Origin of the Term "Design Thinking"

As an approach that drives innovation, the term "design thinking" came about in 2004 based on a catchword in use at IDEO, a design studio in Palo Alto, California. In 2005, Business Week magazine published a special edition entitled "Design Thinking,"[8] thus making it a familiar term across the globe.

There are many different explanations of what design thinking is, but we can sum them up as "taking a designer's approach to try and solve a problem." However, what sort of person a "designer" refers to or "what to do exactly" is open to interpretation, so it is not easy to tell its common definition. IDEO used to have a Tokyo office, but it has since closed (re-opened in 2011), because an insider story tells it overspecialized in industrial design, which concerns shape and form, and it did not develop a business approach that tackled big issues around design thinking. Design thinking as envisaged by IDEO, the company that coined the term, transforms their own business from pure industrial design into a more influential enterprise that we now call design consulting. However, even IDEO do not have the unique definition. Tim Brown, the current CEO who took over from David Kelley, one of its founders, published a paper on design thinking[9] in 2008 and a book[10] in 2009, but even then the wordings are multiple, different words and phrases

[NOTE 2] Although the human-centered element is a basic element of design, here it refers in general to considerations of assessing value for the humans involved, including a product's users. Another term is "human-centered value."
[NOTE 3] For example, according to Yoshio Murata of Nomura Research Institute, Sony's Walkman was the result of cooperative design thinking between three people: an engineer (Masaru Ibuka), a businessman (Akio Morita) and a performance artist (Norio Ohga). This product fulfilled the three elements shown in Figure 1.

are used to describe design thinking processes and elements. Accordingly, the meaning could undergo a certain degree of further change in the future.

2-3 The Design Thinking Process

The IDEO website (http://www.ideo.com/about/) currently has the following paragraph on the design thinking process.

"The design thinking process is best thought of as a system of overlapping spaces rather than a sequence of orderly steps. There are three spaces to keep in mind: inspiration, ideation, and implementation. Inspiration is the problem or opportunity that motivates the search for solutions. Ideation is the process of generating, developing, and testing ideas. Implementation is the path that leads from the project stage into people's lives."

This design thinking process can be analyzed and thought of in many ways. For example, the University of Potsdam in Germany, discussed later in this paper, divides the process into six stages: understand, observe, define point of view, ideate, prototype, and test. The most important thing is that these processes do not progress through the steps in one direction in a certain order. Rather, one can go back and forth, or along a spiral line, providing a deeper understanding of an issue to arrive at a more effective result. Figure 2 illustrates this process, with reference to sources such as Reference #9.

2-4 Human-Centered Thinking and Prototyping

The phrase "human-centered" describes one of the three elements in Figure 1, but it is treated as the core idea of the design thinking approach. People who work in education often use the word "empathy." As ethnologists often employ the methods for ethnography, empathy has a dormant presence among education professionals that many may not be aware of as they employ the concept in their work. However, understanding essential issues is a pillar of the design thinking approach.

In addition, the connection between the ideation part of the process with the following prototyping is important,[11] and that prototype must be assessed.[12] For example, Apple's strength is said to be that it has the ability to build all of its prototypes in-house, despite not having its own factories or doing its own manufacturing.

We could say that human-centered thinking and prototyping have generally been neglected in traditional research and development.

2-5 π-Type Personalities and Highly Diverse Teamwork

A point emphasized from an education viewpoint is educating T-type personalities who follow a single path and π-type personalities who work in multiple areas of expertise.[13] The examples of design thinking in practice outside Japan—as discussed later in this paper—involved highly diverse teams comprising students with different majors and backgrounds. Being able to engage in teamwork with people possessing different specializations is essential to design thinking education. This is the way we should be educating students. Accordingly, Figure 3 combines Figures 1 and 2 to form an overview of design thinking education.

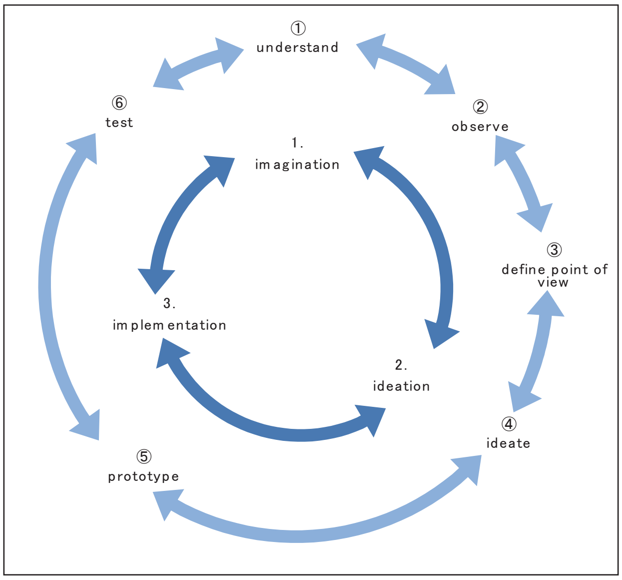

Figure 2 : The Design Thinking Process
Compiled by the Science and Technology Foresight Center

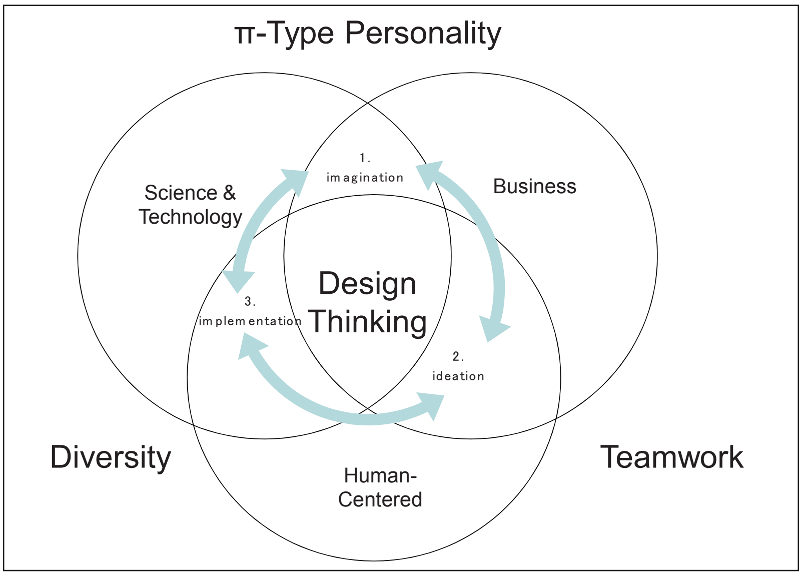

Figure 3 : Design Thinking Education Overview
Compiled by the Science and Technology Foresight Center

3 Design Thinking Education at Work

3-1 Global Universities and Graduate Schools Engaging Design Thinking

Business Week magazine put together a special edition on design thinking in 2009 that presented the top 32 "World's Best Design Schools."[7] Table 1 shows 33 universities and graduate schools that, as far as the author can confirm, have curriculums associated with design thinking. Some of these overlap with the Business Week ranking.

3-2 Design Thinking Education at Stanford University's d.school

The author had a chance to see a project, called The Agile Aging project[13] at Stanford University's d.school. The school has been a pioneer of design thinking education. We use the project to explain to the reader how this sort of teaching is actually being conducted.

3-2-1 From Issue Comprehension to Prototype Building

The goal for Agile Aging is to make life more comfortable for seniors. A team of students first starts out to thoroughly understand the issue. They take trips off campus to observe elderly people's lifestyles and hear their complaints and opinions. Rather than staying cloistered away in the university's classrooms, they go see what is really happening, come back with the experience and information they each obtained and share with the team. The members, with various majors and backgrounds, bring back each of the experiences and information they obtained individually and get to the root of the problem as a team.

Next, they seek out ideas for a solution, engaging in "brainstorming." They may need to go back and look again at the background of the problem during this process. In that case, an approach to the issue from a different angle may be suggested to them. However, we should keep in mind that the driving force behind the production of ideas here is individual inspiration.

A variety of methods are employed to obtain a solid understanding of the issue, including ethnographic methodologies. The term "empathy" comes up a lot here. Being able to think about things from another person's standpoint has the same spirit as the Japanese concept of sangen shugi in manufacturing, which refers to the "three actuals" of the actual location, actual component and actual situation.

After generating ideas, the team begins ideation to form a proposed solution. The important thing here is that ideation is done through teamwork rather than being an individual task, and it is a process of visualization that links these ideas with a visual object in the form of a prototype. A prototype can be understood from the phrase "quick and dirty," meaning that rather than taking the time to build something perfect, one places importance on quickly building something that expresses the key concept.

Table 1 : Examples of Universities & Graduate Schools Implementing Design Thinking Education

Asia-Pacific Region	
Japan	Kyushu University (Graduate School of Design) Kyoto Institute of Technology (Department of Design Engineering & Management) Keio University (Graduate School of Media Design, Graduate School of System Design and Management) Chiba Institute of Technology (Department of Design) Tokyo Institute of Technology (Graduate School of Design Science and Technology) The University of Tokyo (i.school) Tokyo City University (Social Information Department)†
South Korea	KAIST (DESIGN)*
China	Zhejian University: Communication University of China†
Taiwan	Xue Xue Institute
Singapore	Singapore University of Design and Technology Singapore Polytechnic National University of Singapore
India	National Institute of Design* Indian Institute of Technology
Australia	University of Technology, Sydney
Europe	
United Kingdom	Royal College of Art / Imperial College London*
Italy	Milan Institute of Technology
Netherlands	Delft University of Technology* Technische Universiteit Eindhoven
Denmark	Technical University of Denmark Design Skolen Kolding
Germany	University of Potsdam (HPI d.school)
Finland	Aalto University (IDBM)*
France	The École des Ponts ParisTech (d.thinking)
South America & North America	
Chile	Pontificia Universidad Catolica de Chile
Canada	University of Toronto (Rotman School of Management)*
United States	Stanford University (HPI d.school)* Northwestern University* Massachusetts Institute of Technology (System Design Management) Illinois Institute of Technology(Institute of Design)*

* indicates universities and graduate schools presented by Business Week (2009). † indicates a university/graduate school that will open in the 2013 academic year. The universities and graduate schools in this list are implementing design thinking education to varying degrees.

Compiled by the Science and Technology Foresight Center

Furthermore, while attention must be paid to the actual location and ingredients in order to understand the issue, as described above, because a prototype is good enough if it expresses the essential function, it does not necessarily have to be close to the final product at.[NOTE 4] Recently, students have been creating videos to visualize how their prototypes are used and performing skits to show what settings they will be used in.

3-2-2 Participation by Stakeholders and Short Presentations

In addition, the participation of outsiders who are affected by the issue is encouraged in this process of ideation. In the issue of agile aging used here as an example, seniors joined in evaluating the prototype. In normal pedagogy, children are often forbidden from enlisting the help of others to finish making their work, and from this perspective, the approach at design thinking education may seem to be a form of cheating. However, the goal of this education is to explore any possibilities, try various means and, as quickly as possible, demonstrate an effective path to a real solution for the issue (that being the objective). If the person posing the problem has a solution, then it is okay to hear it. Accordingly, involving the people affected by the issue in the process is recommended as a perfectly natural technique. Design thinking education usually pick up the poblems with no final solution is known

Lastly, the team goes before the person posing the problem or other teams' members to give a five-minute presentation. Five minutes seems like a very short time considering all the efforts the students put in until that point. However, because many very important presentations in real life are conducted for incredibly busy leaders, it makes sense that they should be short. Another important element of design thinking education is figuring out how to emphasize the essentials of one's solution in this environment.

3-3 Design Thinking Education's Achievements

The design thinking education process ends with the above-mentioned presentation and feedback from collaborators. Accordingly, the implementation to help those in a predicament—the phase that would follow the formation of ideas and problem-solving—usually does not happen because of time constraints. However, although the university may not officially commit, cases have been reported in which excellent solutions to problems transition to execution and reach the implementation phase.

According to the website for Stanford University's d.school,[6] ideas from some of the designs proposed there have been adopted in the form of ventures and start-ups, as well as by existing companies. For example, venture firms have been established to sell products and services like the D.Light,[20] an alternative to conventional oil lamps, and Embrace,[21] an affordable body warmer for premature babies, in developing countries and elsewhere. Examples of ideas picked up by large firms include Fidelity Investments' remake of its website.[19]

Like Stanford University, the University of Potsdam also provides a case (albeit not announced in written form) in which a company that put forth a problem hired all the members of a student team who had demonstrated a solution and carried out the project. Joint operation of the project between the company and the university over the next few years then led to successful commercialization. Metro, a major supermarket chain, posed a problem concerning new methods of online shopping. The students then proposed a system by which customers who make a purchase online can receive their products at simple storage sites at train stations or on the street. Metro reportedly commercialized a system based on this proposal.

It is said that at private companies, management needs to commit and make an idea part of the company's business strategy in order to take a result produced by design thinking and carry it to commercialization, Otherwise, its chance of success

[NOTE 4] When the author visited Stanford University in 2008, the students made a prototype of a toilet with fold-up handrails for seniors. This team proposed a new toilet as a solution for the issue of agile aging. They put together cheap pieces of plywood with packing tape and attached aluminum foil to substitute for a mirror, and placed a cushion on a nearby chair to substitute for a toilet. Someone from a Japanese university engineering department or company R&D department may think this looks like mere child's play, but that is fine so long as it clearly expresses the concept.

is low.[18] Management needs to be involved for the industry to utilize design thinking.

3-4 Design Thinking Education's Goals

However, the end goal of design thinking education is not the aforementioned implementation, but rather the education of innovators called "design thinkers." Also, design thinking education teaches people to deal with real world problems by forming teams with people from other fields and working on projects to demonstrate solutions, it does not intend to produce individuals but teams and cooperative network of people.

A key aspect of design thinking, which is probably not emphasized so much because it is so apparent, is that "learning from anything" is essential. However, teamwork is also important. In the above-mentioned university program, students are not given grades or certificates of completion. This is because the design thinking approach recognizes that assigning individual grades to members who made various contributions to their team would wreck that teamwork. However, this does not mean a lack of assessment for their results. It is essential to receive evaluations of the solution from the people who posed the problem. They carefully inquire into whether the solution will help and whether it is meaningful. However, this is different from giving grades to individual students; it is an assessment of the team's proposal.

4 Design Thinking Education Administration

Let us look again at the examples of Stanford University and the University of Potsdam to see how exactly design thinking education should be administered.

4-1 The d.school's Administration

Stanford University's d.school is a department within the Hasso Plattner Institute (HPI), created in 2005 within Stanford University with funding personally provided by Hasso Plattner, a one of the founders of SAP AG. Although the school is affiliated with the university, its administration is kept separate. Administration funding comes from the HPI fund, other individual and organizational contributions, as well as selling educational services to companies and other means. The school receives no financial support whatsoever from the university. Unlike typical university schools, no credits are earned for completing the program, no transcript or diploma certifying academic credit is issued and, naturally, students do not receive report cards.

HPI created the University of Potsdam's d.school in 2007 as a place for design thinking education in Germany. At that time it began with the same kind of facilities and administration as the Stanford University d school, but its approach is to gradually introduce successful elements while making its own improvements.

4-2 Student Screening: Ensuring Diversity

The Stanford University d.school and University of Potsdam d.school annually recruit around 350 and 120 people, respectively, during recruitment drives each semester. Both are very popular and attract many applicants. At Stanford's d.school, admission is limited to students enrolled at one of the university's graduate schools. At the University of Potsdam, the German education system allows any graduate students in the Berlin and Potsdam areas to apply, no matter what university they are attending. Many foreign students come to Germany for applications as of late key report in June, 2012.

Student screening considers not only applicants' compatibility with design thinking and their skills, but also ensuring diversity within teams. In other words, the process considers how to build teams composed of members from as diverse a range of majors and backgrounds as possible. What should be emphasized is that the screening gives thorough consideration to individual students' expertise and backgrounds. Teaching π-type personalities is based on solid specializations and demands that individual students already have expertise at the undergraduate level. Education for π-type personalities does not refute specialization, but liberate from "confining oneself within a specialty." Thus, it in fact assumes a high level of specialized education among individuals and a diversity of those specializations.

4-3 Coursework Schedule

The core of the curriculum at each university's d.school is a 12-week series of classes, the main part of which is a workshop. Stanford University offers classes on many topics three times a year: fall, winter and spring. Students can examine the content of the classes prior to applying. The University of Potsdam recruits students every winter and spring semester. The basic course is a nine-week workshop, after which students can take an advanced course up through the twelfth week.

In the workshops, students go through the process described earlier to examine an issue stemming from a real-world problem, build a prototype, and finally present a solution to those who posed the problem and have it evaluated. Students go off-campus to understand their issue, even traveling overseas if necessary. For example, students at the University of Potsdam's d.school came to Japan to study the country's advanced cat litter boxes. However, many prototypes make do with readily available materials and students usually do not seek them out from elsewhere. Some teams also produce video effects to present via video and other media a virtual setting in which their prototype would be used.

4-4 Team Structure and Work Settings

Workshop teams are comprised of a few to 10 or so students, to which two or three facilitators are assigned. A full-time instructor will direct multiple teams as they cover a certain topic. Teams are allocated separate desks and corners to work at. Until the project is completed, the team members can come and go as they progress with their work (see Figure 4). Of course it is standard for team members and facilitators to gather and work during scheduled class hours, but their time is not managed like a typical lecture course, in which everyone assembles at the start time and finishes their work by the end time. And the classroom for lectures is a corner of a design studio with sofas, chairs, tables, whiteboards and other furnishings that students are free to rearrange. Stanford University's d.school makes major changes to the layout and facilities each time its building moves to a new location. Since 2010 it has taken the form of a “War Room” prepared by IDEO and other companies, where student groups can work on each project.

4-5 Faculty

In addition to full-time staff, schools enlist the help of part-time experts in various fields as facilitators. These instructors assist student groups with their projects. Stanford University’s d.school has around 70 facilitators and the University of Potsdam’s has around 40. The instructors are distinguished by their rich diversity as they come from various fields, specializations and backgrounds. At Stanford University, many alumni, including former executives, help with the program.

The most intriguing thing with the faculty is that the instructors themselves have also learned much from the interaction and tried to incorporate ideas for improvement right away. For example, faculty at Stanford University's d.school line up their desks together with the administrative staff's in a layout designed to improve work efficiency. At the University of Potsdam's d.school, rather than sitting to deliberate and work, they find that standing is more efficient, so they started using desks designed to facilitate this style (see Figure 4.). Now they even have licensed promotions for this kind of desks.

Figure 4 : University of Potsdam Student Team Corner

Source: University of Potsdam HPI d.school

4-6 Facilitators

Facilitators are staff members who take care of the teams. Facilitators found come for various fields and possess diverse backgrounds and skills. Facilitators would include alumni and people working in the local area. One facilitator said, “We are not teaching. We watch over the students as they go through a trial-and-error process, make mistakes and run into dead ends. We just help these men and women reach a solution.”

Facilitators’ education is itself a critical element. Some think that popularizing design thinking education is difficult due to a lack of facilitators. However, IDEO General Manager Tom Kelley said, “Where design thinking is taught, facilitators also learn and grow, so there’s no reason to worry about facilitator shortage.”

4-7 External Linkages and Ecosystem

As described earlier, although Stanford University's d.school receives administrative funding from the Hasso Plattner Institute (HPI), to which it belongs, this financial support is limited to a few years and the school is transitioning to an independent status. Naturally, in order to do so the school is building up its outside financing, thus developing its external links and ecosystem. this kind of independent status was made with Mr. Plattner, from the beginning of the Stanford d school.

The University of Potsdam’s d.school is also administered with financial assistance from HPI, but there seems no deadline to make the school independent. However, the University of Potsdam’s d.school was established along with a venture incubation center at HPI and recently numerous venture capital, have been joining in design thinking education presentations and the like. Rather than being a scheme to secure outside funding, this can be thought of as setting up an environment conducive to turning good proposals into start-ups.

Both schools are also actively engaged in design thinking education for companies and working adults, not just graduate students. Individual companies have ways to contact and make requests to both schools. In addition, Stanford University has created the Stanford Executive Program run five times a year, in which individuals and small teams of people from outside the university can participate. The program consists of a three-day introductory course that costs US$9,500 to take. The University of Potsdam runs a three-day course any time of the year in an open course format, which costs 2,750 euros (before tax) to join. The University of Potsdam also limits individual applications, but does offer the Design Thinking for Professionals program that mixes working adults with students.

5 Examples of Other Universities and Graduate Schools outside Japan

This section will introduce design thinking education at universities and graduate schools other than those already discussed (see Table 1). Many universities and graduate schools have begun using design thinking as a slogan in recent years. But they are not specifying what design thinking is. Rather, they are teaching to instill the same kind of thinking. And while some universities and graduate schools are running legitimate programs, and some programs are being set up at universities that already specialized in design or had a design department, much of this design thinking education is happening at business schools.

5-1 European Universities and Graduate Schools

In Europe, the Ecole des Ponts, ParisTech (the National School of Bridges and Roads) set up a d.thinking course in 2009, which unabashedly advocates design thinking. At Finland’s Aalto University, created through a 2010 merger of three universities (Helsinki University of Technology, Helsinki School of Economics, and University of Art and Design Helsinki), the International Design Business Management (IDBM) program has a tradition dating back to 1995, before the merger.

The Innovation Design Engineering (IDE) program has been offered at the Royal College of Arts in the United Kingdom as a design thinking-equivalent two-year program since 1995. Currently, according to Miles Pennington, the head of the department, the program gathers diverse students from as many different regions and majors as possible, and aims to teach by inducing a “chemical reaction” between students to find various problems and propose solutions to them so that there is no syllabus. Design London, an organization created in 2007, offers business funding for prize-winning student work at the Royal College of Arts and Imperial College

London. Design London was disbanded in fiscal 2011 and merged with the InnovationRCA business incubator in April 2012.

Other European universities and graduate schools teaching design thinking can be found in the Netherlands, Italy, Denmark and elsewhere (see Table 1). In Denmark, Design Skolen Kolding is at the heart of the D-City Plan, a local cluster project.

5-2 North & South American Universities and Graduate Schools

In North America, since 2005 the Rotman School of Management at the University of Toronto, Canada has run two design thinking courses: Business Design and Integrative Thinking. Here, Dean Roger Martin encourages design thinking from a business school perspective, and he has written numerous articles on design thinking. In the United States, MIT's School of Engineering and Sloan School of Management jointly run the System and Design Management program, which incorporates design thinking. In Chicago, the Illinois Institute of Technology’s Institute of Design is conducting a similar program. Although the business school programs at Northwestern University, led by Donald Norman, are not officially termed design thinking programs, they include observational visits to real hospitals and automotive design projects, which makes them equivalent to design thinking education.

In South America, Chile also has a program at the Pontificia Universidad Catolica de Chile (Pontifical Catholic University of Chile).

5-3 Asia-Pacific Region Universities and Graduate Schools

Singapore is probably the most active country in Asia when it comes to design thinking education. The Singapore University of Design and Technology began teaching design thinking in 2009 in the form of a joint program with MIT and Zhejian University (China). The Design Singapore Council, set up by the government, established a university-equivalent educational institute in 2010 called the Design Thinking and Innovation Academy, which began teaching design thinking, including knowledge creation elements. The SP School of Design is also teaching design thinking at Singapore Polytechnic. At the National University of Singapore (NUS), the School of Engineering has established a graduate program for Integrative Design Thinking. The university is also promoting design thinking education at the NUS Business School, which has created a Design Thinking & Business Innovation program.

Strong demand by industry in South Korea, China and other countries in the region has led institutes in those countries to begin teaching design thinking. In South Korea, where industry places importance on design in general, the Department of Industrial Design at the Korea Advanced Institute of Science and Technology (KAIST) is heavily promoting design thinking education. Professor Kun Pyo Lee, who played a central role at KAIST, has garnered much attention after transferring from the university to a position as vice president of design at LG Electronics. That fact alone provides the links with industry in this area. In 2012, Communication University of China in Beijing created a department with a focus on design thinking. Professor Weinberg of the University of Potsdam’s d.school is involved. Numerous inquiries have already come in from Chinese companies and foreign companies. Taiwanese industry also has a great interest in design, and the Xue Xue Institute in Taipei plans to incorporate design thinking.

India’s National Institute of Design (NID) was founded in 1961, but it began devoting efforts to design thinking in 2007,[14] when India’s government formulated its National Design Policy.[22] In response, the India Institute of Technology (IIT) later created its own design thinking program. There is also deep interest in design thinking in other countries such as Malaysia and Indonesia.

In Australia, the University of Technology, Sydney is also teaching these concepts.

6 Japanese Universities and Graduate Schools Teaching Design Thinking

There are few curriculums in Japan that use the term “design thinking.” However, the author believes that programs with the same content have been present.

The University of Tokyo’s i.school, started up in 2009, is probably the closest thing to the aforementioned d.schools in Japanese education. It has attracted much attention for being very different from the program at other Japanese universities, in that the school seeks corporate donations and runs project-style workshops.[15] The basics of the program are that it recruits ten graduate students and holds five workshops each academic year.

Of those, students must join three designated workshops to receive a certificate of completion. However, the certificate does not count toward academic credit. The school does not have its own building or rooms. It has held joint workshops outside Japan with South Korea's KAIST, India's IIT and others. Moreover, open workshops allow employees of partner companies and students from other universities to participate as well. At first the i.school mainly targeted graduate students, but since the 2011 academic year it has run programs for freshman and sophomore undergrads at its Komaba campus. i.school alumni, so to speak, has begun u.school[17] for junior high and high school students and others to experience the i.school style workshop for themselves.

Starting in the 2000s, much of what the D. Think Lab at Keio University's Graduate School of Media Design does falls along the lines of design thinking education. In 2008, Keio University created the Graduate School of System Design and Management at the Hiyoshi Campus. This school also includes design thinking in its curriculum. However, neither of these schools are recruiting students from all the university's schools. Their design workshops are regular coursework. A Keio University professer fold us that the intent in establishing the Shonan Fujisawa Campus was to break down existing academic departments, and is equivalent to an effort to promote design thinking.

Design schools like the Graduate School of Design at Kyushu University, the Department of Design at the Chiba Institute of Technology and the Department of Design Engineering & Management at the Kyoto Institute of Technology are also teaching design thinking, but like Keio University, they are not actively trying to mix students from other and different disciplines.

In 2011, Tokyo Institute of Technology, Associate Professor Hiroyuki Umemuro began teaching a Design Thinking course at the Graduate School of Design Science and Technology. Its purpose is to study what exactly design thinking is and it is a half-year program that students from all the university's schools can join. Tokyo City University plans to start a semester-long Design Thinking course for freshmen in the Social Information Department starting in 2013. Meanwhile, the Graduate School of International Corporate Strategy at Hitotsubashi University has been running a Design and Creativity program since 2005. This, too, is very similar to design thinking education.

Although not a permanent program, Kyoto University organized the Kyoto University Design School workshop in September 2011 and March 2012. A number of the university's schools, including the GCOE Informatics Education and Research Center for Knowledge-Circulating Society, the Graduate School of Informatics, the Graduate School of Management, the Graduate School of Engineering and the Academic Center for Computing and Media Studies, collaborated to hold the workshop and recruited participants from outside the university.[16] The International School of Asia, Karuizawa, runs a workshop as a summer school program for junior high school students from around the world.

Japanese companies are also interested in workers with design thinking capabilities and are beginning to hire students who have experienced its concepts as described above. Toshiba Corporation is recruiting students who have completed the University of Tokyo's i.school program and graduates of non-Japanese universities such as KAIST in order to acquire workers the company needs for its infrastructure business. Meanwhile, Nomura Research Institute, Ltd. and the NTT Data Institute of Management Consulting, Inc., seeing a limit to the software contracting business and its traditional business model, are building the Future Center, which will comprise a corps of employees specializing in design thinking.

7 Conclusion

While there is some variation to how the term, design thinking, an education approach, is used and the content of design thinking programs, it is in the process of spreading and growing worldwide. The traditional approach to education, premised on the assumption that acquiring the latest knowledge and skills in a specific field or industry will lead to innovation, is becoming obsolete. It can be expressed by a phrase often used by the Japanese media: "Japan is winning with technology, and losing in business."

Meanwhile, universities and graduate schools across the globe are beginning to incorporate design thinking education and praising it as an educational method that will produce results to address the wide-ranging and spanning from social problems to the future problems—including those in as yet unknown fields—by forming teams comprising members with various specialties.

And as like many other educational and training approaches, design thinking is not a cure-all that "can make anyone into an innovator." And there is no fast and easy way to learn design thinking. As of now, there is no certificate we can issue that says someone has "acquired" design thinking. Accordingly, the author believes that taking the simple step of "setting up design thinking departments at many universities and graduate schools" would not be effective.

Finding a way to promote the spread of design thinking education may itself be an issue that we should work out with a design thinking approach. For example, there is not yet any place in Japan that is teaching design thinking like predecessors elsewhere in the world. Thus, it may be effective for Japan if educators promoting design thinking were to experiment in new ways by collaborating in a utilization of applicable settings, equipment, tools and the like.

Even in Japan, some universities and graduate schools are already starting to teach something thought to be near design thinking education. There is no standard teaching process, so the author believes that each university and graduate school should move forward in its own way. However, none of them has a program that properly shares its students' results with the outside world when they find an area for improvement. Accordingly, these programs are not producing meaningful results for society. We could think of new methods in addition to a framework for sharing results, producing videos and publications or even collaborating in running design thinking programs. Improving on those kinds of areas would lead to praise for the results produced by this form of education.

Naturally, in addition to instructors and facilitators capable of teaching people innovation, we also need people who can correctly assess innovators and who are working out in the world.[4] This is why one way to expand design thinking education is to cast a wide international network to collect innovative ideas and to share the various efforts being made in Japan with educators overseas.

However, an important thing to do first is to not get caught up in a traditional paradigm, but rather to understand the intent of design thinking and to foster a mentality of actively supporting these initiatives. In addition, if we set up places where the public can experience an embodiment of this approach and focus on relationships outside academia, it will probably lead to change in education ever in gradual, incremental manner.

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References

[1] Richard S. Rosenbloom & William J. Spencer (Eds.), ENGINES OF INNOVATION - U.S. Industrial Research at the End of an Era, Harvard Business School Press, 1996

[2] 4th Basic Science and Technology Plan, 2011: http://www8.cao.go.jp/cstp/kihonkeikaku/kihon4.html

[3] Ministry of Education, Culture, Sports, Science and Technology: Service Innovation Education and Training Plan: http://www.mext.go.jp/a_menu/koutou/service/index.htm, 2007, Japan Keidanren: Aiming for Education for and Work by Science and Technology Professors to Generate Innovation: http://www.keidanren.or.jp/japanese/policy/2007/020.html, 2007, etc.

[4] Ministry of Economy, Trade and Industry: Industrial Talent Policies: http://www.meti.go.jp/policy/economy/jinzai/frontier-jinzai/index.html, 2012

[5] The following reports on training and education have appeared in "Science & Technology Trends": "Educating Life Science Researchers and Proper Educational Methods"(Oct 2002), "Education in the Nuclear Power Sector: Necessity, the Current State and Related Issues"(Sept 2003), "Education Upholding International Standards"(June 2005), "Analog Technology Trends and the Importance of Education and Training – Focus on a New Age of Analog Technology Found in CMOS High-Frequency LSI"(Jan 2007), "The Image of Clinical Researchers Needed for the Future and Educational Experiments at Graduate Schools"(Aug 2007), "Industrial Growth in India Founded on IT and Educational Trends Aiming for a Knowledge Society"(Sept 2007), "The IT Worker Problem as a Japanese Crisis"(July 2008), "Educating Workers to Support Japan's International Industrial Competitiveness – Educational Models Using Exemplified by Steel, a Key Industry" (Apr 2009)

[6] http://dschool.stanford.edu/social-entrepreneurship/, an example of success: http://embraceglobal.org/, etc.

[7] World' Best Design School, Special Issue "Design Thinking," Business Week 2009/0930: http://images.businessweek.com/ss/09/09/0930_worlds_best_design_schools/index.htm?technology+slideshows

[8] Tim Brown, "Design Thinking," BusinessWeek 2005/3/8

[9] Tim Brown, Design Thinking, Harvard Business Review, June 2008, pp.85-92

[10] Change by Design: How Design Thinking Transforms Organizations and Inspires Innovation, HarperBusiness, 2009 ("Design Thinking Can Change the World – New Thinking Leading to Innovation," Hayakawa Shinsho Juice), 2010

[11] Naohito Okude, The Design Thinking Toolbox, Hayakawa Shobo, 2007 (in Japanese)

[12] Kinya Tagawa, Design Engineering: Innovation Report from the Field, text from NISTEP lecture, 267, Dec 2010 (in Japanese)

[13] Susumu Hayashi and Toshiaki Kurokawa, The IT Worker Problem as a Japanese Crisis, Science & Technology Trends, July 2008

[14] http://designthinkingwebredesign.wordpress.com/2010/11/21/singapore-design-thinking-and-innovation-academy-too-late/

[15] The University of Tokyo i.school, The University of Tokyo's Style of Creating World-Changing Innovation, Hayakawa Shobo, 2010 (in Japanese)

[16] http://www.ai.soc.i.kyoto-u.ac.jp/design/index.html, http://www.ai.soc.i.kyoto-u.ac.jp/design2/index.html

[17] https://www.facebook.com/?ref=home#!/pages/uschool/237458062974981

[18] Naohito Okude, Design Thinking and Management Strategy, NTT Publishing, 2012 (in Japanese)

[19] F. S. Leichter, How Fidelity Used Design Thinking to Perfect Its Website: http://blogs.hbr.org/cs/2011/05/how_fidelity_used_design_think.html

[20] http://business.rediff.com/slide-show/2009/dec/23/slide-show-1-worlds-cheapest-solar-lamp.htm

[21] http://dschool.stanford.edu/blog/2010/01/28/embrace-at-ted/

[22] http://www.designinindia.net/design-now/design-policy/index.html

Profiles

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Building Damage Depending on Earthquake Vibration Period and New Technology Issues

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1 Introduction

The 2011 Off the Pacific Coast of Tohoku Earthquake (hereafter the "2011 Tohoku Earthquake") that caused the Great East Japan Disaster left approximately 20,000 people dead or missing. It was the worst natural disaster to strike Japan since the Great Kanto Earthquake of 1923. However, the damage caused by the ground motion of the earthquake has not received much attention because most lives were claimed by the tsunami. In fact, ground motions of the earthquake also caused various kinds of damage, and tracing what has occurred is the only way of the research of seismic hazard. We need to look at the fact revealed by the unprecedented disaster, and to draw lessons from the fact in a humble attitude.

The National Institute of Science and Technology Policy (NISTEP) held a seminar entitled "Damages Caused by the Great East Japan Earthquake and New Concept of Disaster Prevention" on February 7, 2012. One of main themes of the seminar was the building damage that ground motion directly causes. The speakers and their lecture titles were:

1) "Building Damage from Ground Motions and Problems with Disaster Prevention Systems" by Yuki Sakai (University of Tsukuba)
2) "Impact on Business Activity and the Effects of Seismic Isolation and Vibration Damper" by Shigeki Sakai (Hazama Corp.).

In this report, we present the characteristic features of the building damage caused by the 2011 Tohoku Earthquake based on the seminar lectures. The earthquake destroyed fewer houses and caused less building damage than the 1995 Southern Hyogo Prefecture Earthquake (i.e. the Great Hanshin-Awaji Earthquake) did. The 2011 Tohoku Earthquake mostly caused damage to non-structural members such as tiled roofs and walls. The main theme of this seminar was to clarify why the 2011 Tohoku Earthquake, which had a high seismic intensity, collapsed few buildings due to its shaking. To contribute to reducing damage in future earthquakes was also one theme of this seminar.

The 2011 Tohoku Earthquake generated the short-period ground motion in most of the Tohoku region near the hypocenter. In the Tokyo metropolitan area, however, long-period components were also observed, giving the first experience for the super-high raise building to sway widely for long minutes.

The Tokyo near-field earthquake, which is considered highly likely to occur with a maximum seismic intensity of 7 in the next few years, would cause more massive damage to buildings than the Southern Hyogo Prefecture Earthquake did. Are the buildings in the Tokyo metropolitan area, including the super-high rise buildings, safe enough for the coming earthquake? If there are countermeasures against the earthquake, what are they? The authors would like to try and find some approaches to address such problems and hope to reduce the earthquake damage as much as possible.

As mentioned above, the purpose of this paper is to present the contents of the seminar as well as to learn lessons on building damage caused by seismic shaking in case of a future massive earthquake.

2 Survey Methods and Results on Building Damage Caused by Ground Motion

It is desirable to conduct detailed investigation on damaged buildings in order to secure subsequent safety. However, even if we surveyed all damaged buildings, we cannot obtain the percentage of damaged buildings because it gives only the total number of damaged buildings. The damage rate or the collapse rate can only be derived by uniformly surveying all buildings in the whole area, irrespective of the damage status.

In practice, it is impossible to survey all buildings in a broad area, and even if one did, the indiscriminate survey would not reveal the relationship between the damage and seismic intensity or shaking. An effective approach to clarify such relationship is to select locations with reliable seismographs installed and to survey all buildings and houses around the seismograph within a few hundred meter radius.

Thus, there are two methods for surveying building damage; a method to survey only damaged buildings and thereby derive the total number of damaged buildings, and a method to survey all buildings around certain seismographs regardless of their damage and derive the relationship between the damage rate and the ground motion.

In Japan, the National Research Institute for Earth Science and Disaster Prevention (NIED) has seismograph networks called K-NET and KiK-net consisting of 1,381 strong-motion observation stations[1] installed at intervals of about 20 km nationwide (see Fig. 1). In addition, the Japan Meteorological Agency (JMA) and local governments each have strong-motion observation stations at 608 and 2,839 locations, respectively.

These observation stations are equipped with a strong-motion seismograph capable of recording strong shaking and a data transmission device, and all of them is enclosed in a sturdy case on the ground (see photo in Fig. 1). A KiK-net station is an observation station comprising a pair of a subsurface seismograph and a surface strong-motion seismograph. The records of seismic waveforms and other data obtained through the K-NET and KiK-net are released to the public or delivered through the internet.[2] When the 2011 Tohoku Earthquake struck, 200 stations of strong-motion seismograph recorded the seismic intensity larger than 6-weak.

Yuki Sakai and his research team selected 35 locations (shown in Fig. 2) out of the 200 strong-motion seismograph stations to survey, excluding locations where buildings or houses are too few. They conducted their field survey from March 16 to April 10, 2011 at 16 locations in Miyagi prefecture, 7 locations in Fukushima prefecture, 6 locations

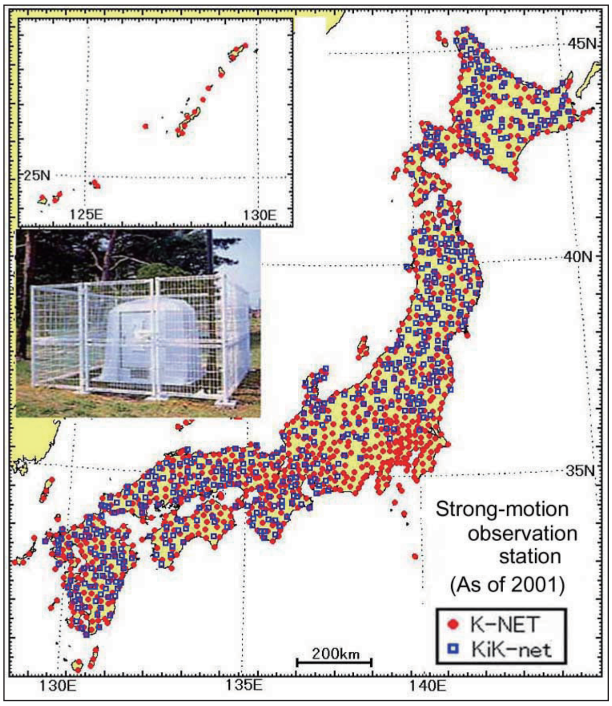

Figure 1 : Location of Strong-Motion Observation Stations K-NET and KiK-net. (Reprint from Ref. 1)

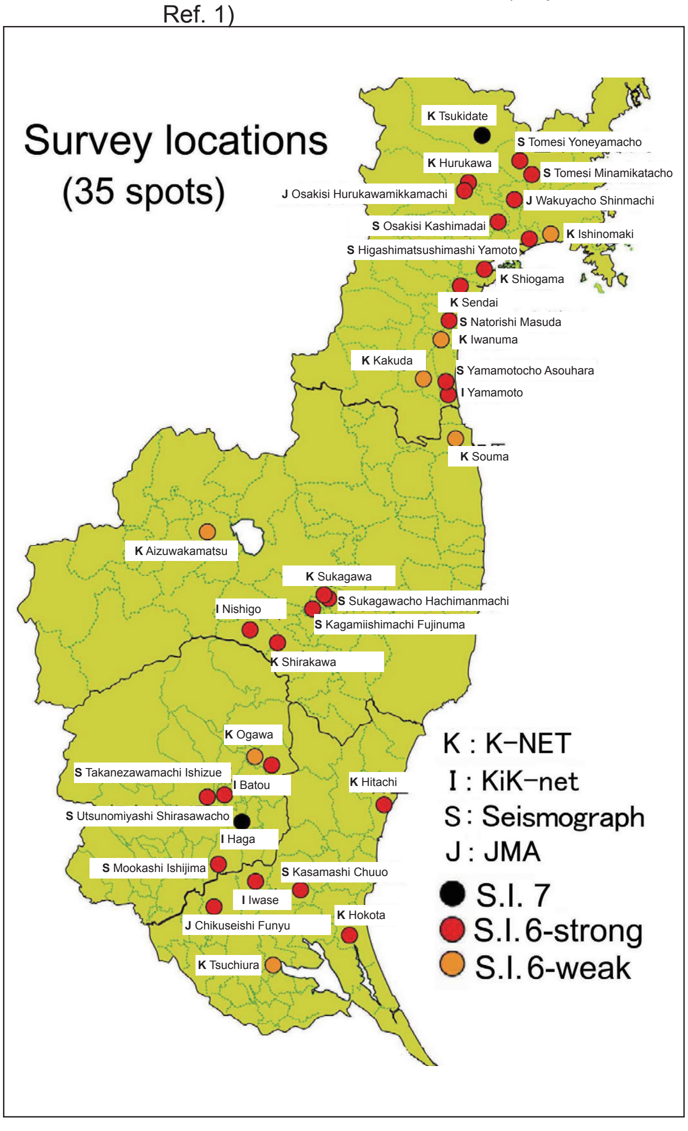

Figure 2 : 35 Locations of Building Damage Survey: (Provided by Y. Sakai)

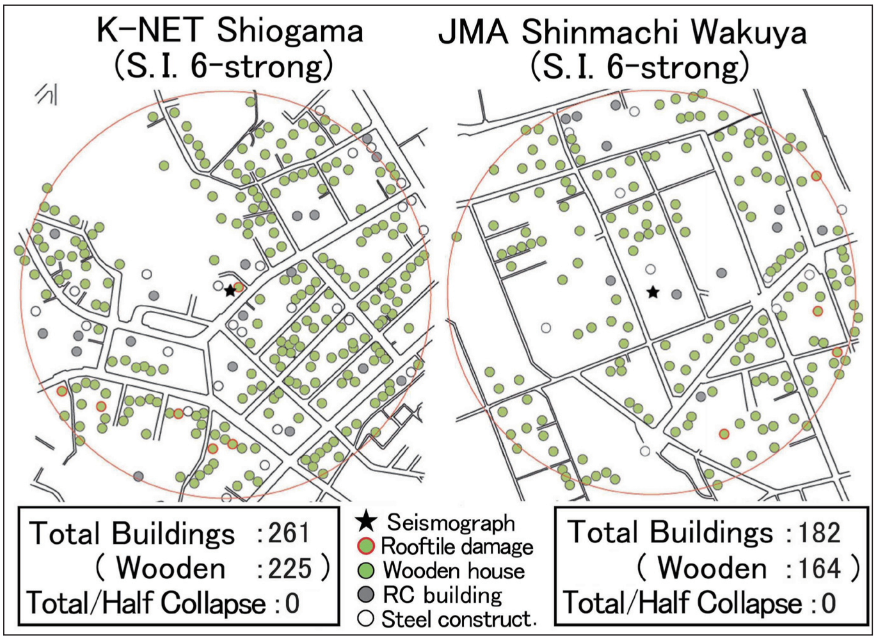

Figure 3 : Examples of Building Damage Survey (Provided by Y. Sakai)

in Tochigi prefecture, and 6 locations in Ibaraki prefecture. In terms of seismic intensity, the seismic intensity 7 was recorded at two locations, the intensity 6-strong at 26 locations, the intensity 6-weak at 7 locations.

Their method of field survey is a visual damage inspection of all buildings and houses in the area within a radius of 200 meters from the each strong-motion seismograph station. They, however, excluded the damage to warehouses and garages and the damage caused by landslides for the purpose of the accuracy. They limited the survey area within a radius of 200 meters from a strong-motion seismograph because the ground motion experienced in the area is expected to be the same as the recorded one. In some cases, however, a building may experience the stronger ground motion than the recorded one depending on the developing method of housing land.

In the field survey, from outward appearance, they judged all buildings in the area as total collapse, partial destruction, no damage or others. They also plotted them on a map, adding other information: the tiled roof damage, the number of floors, and the structural members such as wooden, reinforced concrete (RC) or steel framed structure. The maps in Fig. 3 show examples of field survey at the K-NET Shiogama observation station (left-side figure) and the JMA's observation station in Wakuya town (right-side figure). The boundary of surveyed area is denoted by the circle with a 200 meter radius from each observation station marked by a star. In these two areas, there were no buildings collapsed or seriously damaged, but some roof tiles were slightly damaged. The building damages were not serious also in other area surveyed by them.

Table I shows the overall results of their survey, including the numbers and percentages of building damage. Most surveyed locations experienced a seismic intensity larger than 6-strong (i.e., larger than 6.00), though some locations 6-weak (but almost 6-strong). They inspected a total of 2,954 buildings and houses, of which 0.47% collapsed or seriously damaged.

In Japan, we had defined the seismic intensity of 7 as a ground motion during which 30% or more buildings collapsed. After the definition was replaced by instrumental seismic intensity in 1996, the ground motion with a seismic intensity of 6-strong is supposed to destroy 8% to 30% of buildings, and that with a seismic intensity of 7 is supposed to destroy 30% or more buildings. However, the observed percentage of collapsed or seriously damaged buildings during the 2011 Tohoku Earthquake is as extremely low as 0.47% even in areas that experienced seismic intensity of almost 6-strong or greater.

The method of surveying all buildings within a radius of 200 meters around a strong-motion observation station enables us to obtain the collapse ratio of buildings or the percentage of damaged buildings. It also enables us to compare the collapse ratio to the ground motion there. In spite of such a merit, there is a demerit that buildings outside the

Table I : Results from the Building Damages Survey

Observation Station	Instr. Seismic Intensity	Bldgs.	Collapse	Collapse rate (%)	Observation Station	Instr. Seismic Intensity	Bldgs.	Collapse	Collapse rate (%)
JMA , Osaki (M)	6.21	257	7	2.72	K-NET Furukawa (M)	6.16	285	0	0.00
JMA Funyu, Chikusei (I)	6.06	27	0	0.00	K-NET Hokota (I)	6.41	17	0	0.00
JMA Shinmachi, Wakuya (M)	6.02	182	0	0.00	K-NET Tsuchiura (I)	5.63	161	0	0.00
KiK-net Iwase (I)	6.24	17	0	0.00	K-NET Hitachi (I)	6.46	108	0	0.00
KiK-net Nishigou (F)	6.00	8	0	0.00	Fujinuma, Kagamiishi (F)	6-strong	169	0	0.00
KiK-net Batou (T)	6.14	14	0	0.00	Hachiman, Sukagawa (F)	6-strong	229	5	2.18
KiK-net Haga (T)	6.50	59	0	0.00	Shirasawa, Utsunomiya (T)	6-strong	116	0	0.00
K-NET Ogawa (T)	5.97	146	1	0.68	Chuo, Kasama (Ib)	6-strong	101	0	0.00
K-NET Aizuwakamatsu (F)	5.86	199	0	0.00	Ishizue, Takanezawa (T)	6-strong	155	1	0.65
K-NET Iwanuma (M)	5.99	87	0	0.00	Asouhara, Yamamoto (M)	6-strong	108	0	0.00
K-NET Kakuda (M)	5.83	159	0	0.00	Ishijima, Moka (T)	6-strong	76	0	0.00
K-NET Shiogama (M)	6.02	261	0	0.00	Kashimadai, Osaki (M)	6-strong	123	0	0.00
K-NET Shirakawa (F)	6.11	85	0	0.00	Minamikata, Tome (M)	6-strong	3	0	0.00
K-NET Sukagawa (F)	6.00	75	0	0.00	Yoneyama, Tome (M)	6-strong	18	0	0.00
K-NET Sendai (M)	6.38	21	0	0.00	Higashimatsushima (M)	6-strong	200	0	0.00
K-NET Sohma (F)	5.85	159	0	0.00	Masuda, Natori (M)	6-strong	181	1	0.55
K-NET Tsukidate (M)	6.67	59	0	0.00	K-NET Ishinomaki (M)	5.93	–	–	–
					Total (but >S.I. 6.00)		2,954	14	0.47

M: Miyagi pref. F: Fukushima pref.
T: Tochigi pref. I: Ibaragi pref.

survey area cannot be inspected even if they collapsed. This is because arbitrary expansion of the survey area makes the statistical result unreliable.

In parallel to the above survey, another research group conducted a conventional survey where they closely inspected damaged buildings. Researchers of the National Institute for Land and Infrastructure Management (NILIM) and the Building Research Institute (BRI) jointly studied the damage status of RC buildings and steel-framed buildings within Fukushima prefecture[3] (Miharu town, Nihonmatsu city, Koriyama city, and Fukushima city) and Fukushima and Miyagi prefectures[4] (Shirakawa city, Sukagawa city, and Sendai city).

The survey results again showed that the earthquake with large seismic intensity did not cause heavy damage to many buildings aside from rare exceptions. There were some damages on exterior walls, but damages of the structural member were not serious. The group also reported that many of seriously damaged buildings were built before the 1978 Off Miyagi Prefecture Earthquake. In addition, they also indicated the influence of the ground conditions, because buildings in the area that was previously a paddy field were damaged more heavily.

Thus, two independent surveys clearly show that the damage to buildings caused by the 2011 Tohoku Earthquake was small in spite of the large seismic intensity. Was this the result of increasing earthquake-resistant buildings, or the result of some characteristics in the earthquake vibration? To figure this out, the next chapter attempts to draw comparisons with ground motion caused by the 1995 Southern Hyogo Prefecture Earthquake (the Great Hanshin-Awaji Earthquake), which inflicted considerable damage on buildings.

3 Comparison Between the 1995 Southern Hyogo Prefecture Earthquake and the 2011 Tohoku Earthquake

3-1 Comparison of Ground Motions

In Fig. 4, we compare the typical ground motion of the 2011 Tohoku Earthquake and that of the 1995 Southern Hyogo Prefecture Earthquake (hereafter, the 1995 Southern Hyogo Earthquake). These ground motions were observed at K-NET Tsukidate in Miyagi prefecture and the Takatori Station (of West Japan Railway Company) in Hyogo prefecture, respectively. While the building collapse rate for Tsukidate was 0% at seismic intensity 7, the rate for Takatori was 59.4% at seismic intensity 6-strong, showing a large difference.

The characteristics of the two ground motions shown in Fig. 4 are quite different from each other. While strong short-period ground motion continued for a long time in the 2011 Tohoku Earthquake, relatively long-period ground motion was observed in the 1995 Southern Hyogo Earthquake. The vertical axes of upper two graphs represent the acceleration of

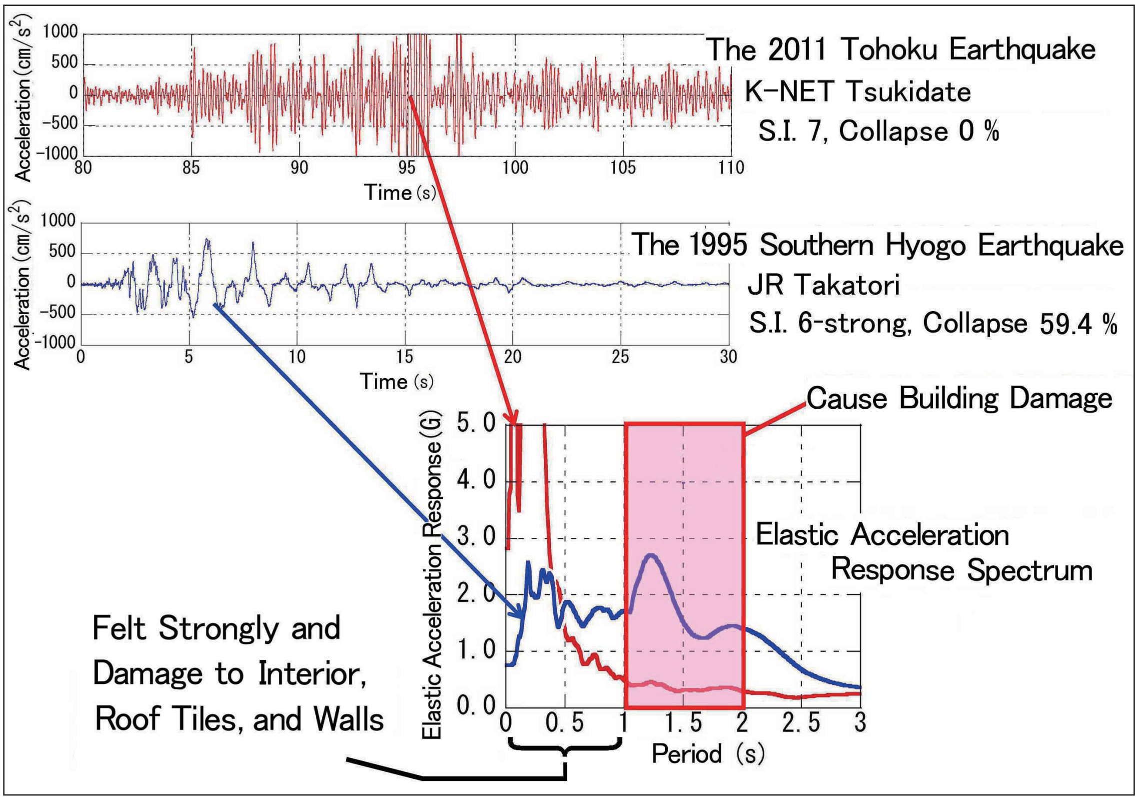

Figure 4 : Comparison of Ground Motions in the 2011 Tohoku Earthquake and the 1995 Southern Hyogo Prefecture Earthquake. (Provided by Y. Sakai)

ground motions in units of cm/s^2, which we usually call as "gal." Another unit "G," where 1G = 980 cm/s^2 (gravitational acceleration), is used for acceleration response in the lower figure. In the graph for the 2011 Tohoku Earthquake, the maximum acceleration exceeded 1,000 gal, but we have omitted the part beyond 1,000 gal to simplify the graph.

The difference between the characteristics of the two ground motions becomes apparent when we draw a graph showing the relationship between vibration intensity and vibration period (i.e., the elastic acceleration response spectrum). The elastic acceleration response of the 2011 Tohoku Earthquake was larger at a vibration period of 0 to 0.5 seconds, but that of the 1995 Southern Hyogo Earthquake was larger at a vibration period of 1 to 2 seconds. The ground motion with a period of 1 to 2 seconds will cause building damage, and it is suggested that there is a correlation between the intensity of this period vibration and the percentage of damaged buildings. On the other hand, ground motions with a period of 0 to 1 second are felt more by people and have a correlation with damages of room interior and non-structural materials such as roof tiles and walls.

Other observation stations in Tohoku region also showed that the elastic acceleration response was large in a period of 0 to 0.5 seconds and small in a period of 1 to 2 seconds (see Fig. 5). This result reveals the reason why the 2011 Tohoku Earthquake did not inflict so much damage to buildings. Namely, it was because the earthquake had little ground motion that affects buildings.

This fact does not mean that the earthquake safety of buildings was improved after the 1995 Southern Hyogo Earthquake. Thus, we cannot automatically expect that a building will withstand a large earthquake in the near future just because it survived the massive Tohoku Earthquake.

It is known that most wood-frame houses and low-

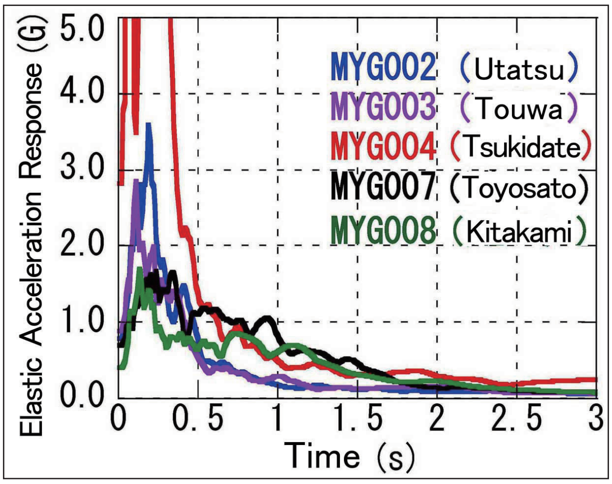

Figure 5 : Spectrum of the Elastic Acceleration Response at Other Observation Stations. (Provided by Y. Sakai)

and medium-rise buildings have their own natural periods of 0.3 to 0.4 seconds, at which they vibrate most easily. Therefore, it may seem strange that ground motion with 1 to 2 second periods, which are longer periods than own natural periods, would cause massive building damage.

The condition of natural period of 0.3 to 0.4 seconds is satisfied only within the elastic limit of buildings. When a building vibrates beyond the elastic limit, the plastic deformation of building starts to occur, and then the resonant period of the building would become longer. Thus, building damage is determined by the longer "equivalent period" at the time of plastic deformation. This has been confirmed by the results of both non-linear simulations and model experiments (see Fig. 6). Ground motion with a period of one to two seconds, even if it is a single cycle, can produce plastic deformation of a building and inflict heavy damage. For that reason, it is occasionally referred to as a "killer pulse" in media reports.

3-2 Comparison of Building Damage

The 1995 Southern Hyogo Earthquake inflicted heavy damage to buildings, fully or partially destroying approximately 250,000 buildings and houses. About 80% of the 6,432 people killed were, reportedly, crushed to death when their houses collapsed. In many cases, people sleeping on the first floor in a two-story house were crushed to death by the second floor dropped due to a broken post.

Ashiya city, a city with a population of about 90,000 people, published a detailed report titled "Ashiya City: Damage to Buildings and Restoration of Them[5]," which included results of all building survey in the city. Among all 15,421 buildings in the city 4,722 were fully destroyed and 4,062 were partially destroyed, accounting for 57% of all buildings in the city. There were 10,514 wooden houses, which were the most in number, and about 70% of them were fully or partially collapsed. Meanwhile, just over 20% of 2,577 RC buildings, which were the second in number, were fully or partially destroyed.

Many houses damaged by the earthquake were built before the June 1981 amendment to the Building Standards Act. Moreover, the older they are, the more houses are seriously damaged (see Fig.7). At some places in the belt zone of a seismic intensity of 7 stretching east to west on the center of the city, more than 90% of buildings and houses were fully or partially collapsed. Many people were also hurt or killed in the belt zone.

The phenomenon of the upper floor dropping due to the snap of posts is called "story collapse." The story collapse occurred not only in wooden houses, but in steel-framed and RC buildings (see Fig. 8). Fortunately, the story collapse in large buildings did not kill many people because the 1995 Southern Hyogo Earthquake struck in the early morning, at 5:46 a.m. We can easily imagine that the story collapse would have killed many people in large buildings such as department stores if the earthquake occurred during the daytime.

Y. Sakai found that the ground motions during the 2011 Tohoku Earthquake did not damage many buildings: the percentage of fully or seriously

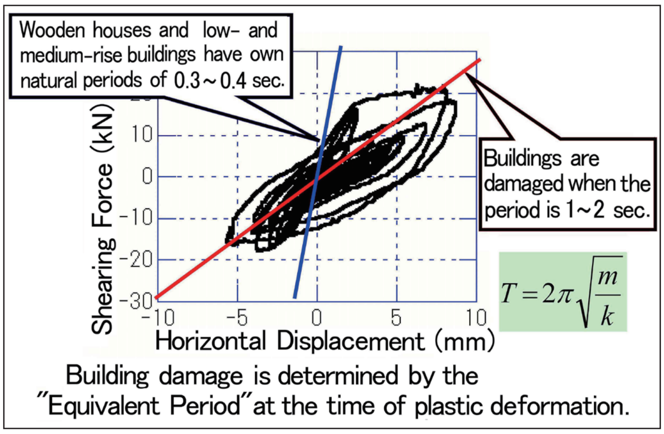

Figure 6 : Result of Model Experiment (Provided by Y. Sakai)

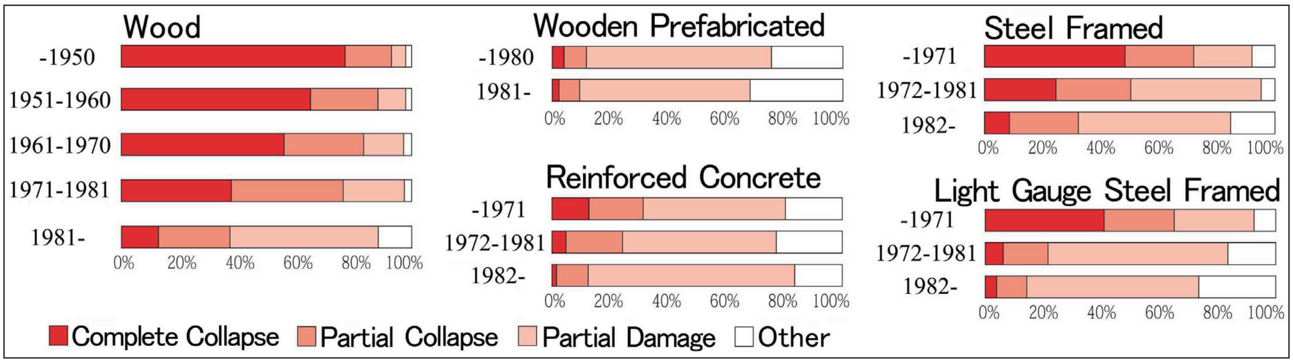

Figure 7 : Damage Situation of Buildings in Ashiya City (Reprint from Ref. 6)

destroyed buildings and houses was only 0.47%. In the meantime, the joint team of the NILIM and the BRI reported that some buildings suffered heavy damages such as story collapses.[3,4]

Figures 9(a) and 9(b) show two RC buildings that faced different intersections. Both buildings had stores on the first floor with "pilotis" structure (soft-first-story structure) which had few bearing walls. In both cases, the corner post facing intersection experienced shearing failure, which caused story collapse. However, a pilotis building with only pillars on the first floor hardly receives flowing water pressure if it can withstand the earthquake. In fact, there was a pilotis building escaping damage from the tsunami. Figure 9(c) shows a university building whose poor earthquake resistance had previously been pointed out. A reinforcement plan had been worked out when the earthquake struck. This building was seriously damaged, but an adjacent building on the same campus had no visible exterior damage. Figure 9(d) shows an example of wall damage that was the most commonly observed form of partial damage.

As discussed above, ground motions with a period shorter than 0.5 seconds were remarkable during the 2011 Tohoku Earthquake, and they mostly damaged interiors and non-structural members such as walls. Because of falling ceiling materials and light fixtures and because of collapsing parking garage ramps, there were casualties even in the Tokyo metropolitan area.

Figure 8 : Story collapse of Large Buildings. (Provided by Y. Sakai)

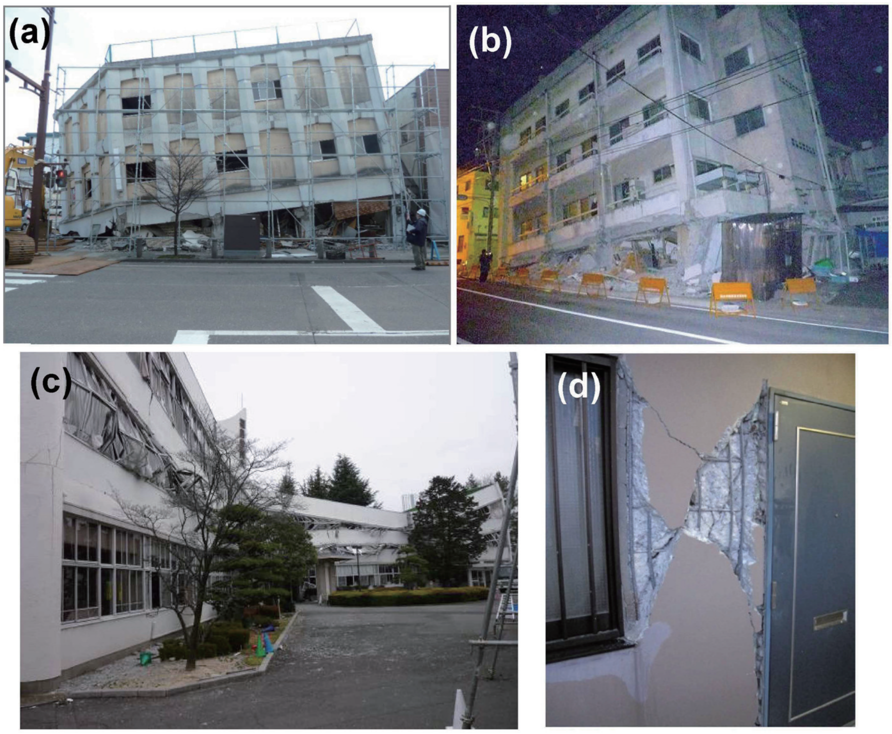

Figure 9 : Examples of building damage due to the 2011 Tohoku Earthquake. (Reprint from Refs. 3 and 4)

In the area, some houses experienced damage such as loosened roof tiles, and other damage was caused by soil liquefaction.

Some manufacturing buildings were also damaged with falling ceilings and broken interiors. An electronic component factory reported that air-tightness could not be maintained because the expansion joint of a clean room came lose. Many factories received large economic loss not only from damage to buildings, but also from damage to production facilities, such as the overturning of manufacturing equipment. Factory damage of a single company had substantial effects on many industries through the supply chain. For example, the shutdown of a semiconductor factory of Renesas Electronics Corporation heavily affected automobile production worldwide.

In order to prevent such an economic loss, industries should have "disaster resistance capability" for avoiding a decline of business activities at the time of a disaster as well as "disaster response capability" for quick recovery of business activity after a disaster. Business operators may need to prepare a "Business Continuity Plan (BCP)" that takes these two points into consideration and involves good practices.

4 Building Damage in Past Earthquakes

We refer to a ground motion where a period of one second or less is noticeable as "short period ground motion," and that where a period of one to two seconds is noticeable as "slightly short period ground motion." When a ground motion mainly involves vibrations with a period of two seconds or longer, it is referred to as "long period ground motion," which has been observed in sedimentary plains such as the Kanto Plain, the Nobi Plain or the Osaka Plain. A long period ground motion is occasionally sorted into more detailed categories; "slightly long period ground motion" with a period of two to five seconds and "long period ground motion" with a period of five seconds or more.

Table II shows the situation of damage caused by past earthquakes larger than a seismic intensity of 6-weak. In the table, the earthquake that caused slightly short period ground motions (with a period

Table II : Damage Situation due to Past Earthquakes Lager Than Seismic Intensity (S.I.) of 6 weeks

Year	Name of Earthquake or Location of Hypocenter	M	Max. S.I.	Tsunami (meters)	Dead & Missing	Building Collapses		Vibration Period
						Compete	Partial	
1995	The Southern Hyogo Pref. Earthquake	7.3	7	Yes	6,437	104,906	144,274	☆
1997	Satsunan Region in Kagoshima Pref.	6.4	6-w	No	0	4	31	
1998	Northern Part of Iwate Pref.	6.2	6-w	No	0	0	0	
2000	Niijima, Kohzushima, and Vicinities (3 Times)	6.5	6-w	0.14	1	15	20	
2000	The Western Tottori Pref. Earthquake	7.3	6-s	No	0	435	3,101	○
2001	The Geiyo Earthquake	6.7	6-w	No	2	70	774	
2003	Off Miyagi Pref.	7.1	6-w	No	0	2	21	
2003	Northern Miyagi Pref.	6.4	6-s	No	0	1,276	3,809	Unknown
2003	The Off Tokachi Earthquake	8.0	6-w	2.55	2	116	368	
2004	The Niigata Pref. Chuetsu Earthquake	6.8	7	No	68	3,175	13,810	○
2005	West-off Fukuoka Pref.	7.0	6-w	No	1	144	353	
2005	Off Miyagi Pref.	7.2	6-w	0.12	0	1	0	
2007	The Noto Peninsula Earthquake	6.9	6-s	0.22	1	686	1,740	○
2007	The Niigata Pref. Off-Chuetsu Earthquake	6.8	6-s	0.32	15	1,331	5,709	○
2008	The Iwate-Miyagi Inland Earthquake	7.2	6-s	No	23	30	146	
2008	Northern Coast of Iwate Pref.	6.8	6-w	No	1	1	0	
2009	Suruga Bay	6.5	6-w	0.36	1	0	6	
2011	The Off the Pacific Coast of Tohoku Earthquake	9.0	7	9.3+	19,263	128,582	244,031	
2011	Near Border between Nagano and Niigata Prefs.	6.7	6-s	No	3	73	426	
2011	Eastern Shizuoka Pref.	6.4	6-s	No	0	0	103	

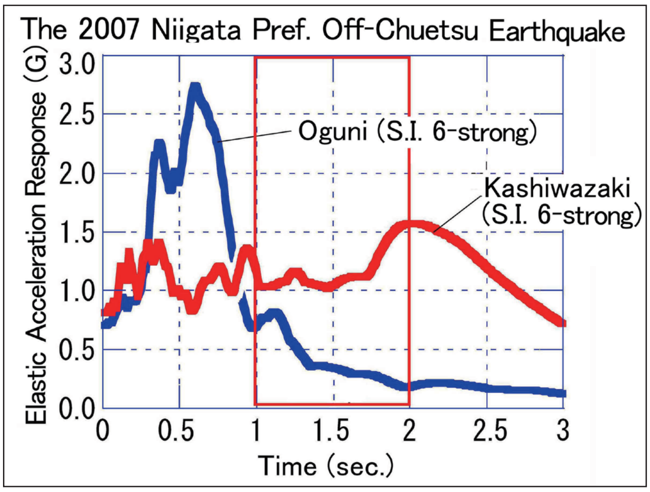

Figure 10 : Spectrum of Elastic Acceleration Response in the 2007 Niigata Pref. Off-Chuetsu Earthquake. (Provided by Y. Sakai)

of one to two seconds) at many locations is denoted by an asterisk, and at limited locations by a circle. It is unknown whether the 2003 earthquake with hypocenter in Northern Miyagi Prefecture caused slightly short period ground motions because some of the seismograph traces were lost. In Table II, we may find that there is a strong correlation between a star or circle and the number of buildings damaged. The 2011 Tohoku Earthquake seriously damaged a large number of buildings, but most of them were damaged by the tsunami rather than by ground motion. On the morning following the 2011 Tohoku Earthquake, however, the earthquake with hypocenter near the Border between Nagano and Niigata seriously damaged many houses in Sakae village (Nagano prefecture) and Tokamachi city (Niigata prefecture).

Though Table II marks earthquakes that caused slightly short period ground motions at some locations, the period is determined not only by the seismic source process but largely by the ground condition there and the propagation path of seismic waves. This is clear from Fig. 10 that shows the elastic acceleration responses observed in Nagaoka city (the Oguni district) and Kashiwazaki city during the 2007 Niigata Prefecture Off-Chuetsu Earthquake. While the short period ground motion was predominant in Oguni district, the ground motion with a period of two seconds or more was in Kashiwazaki city. In this way, the vibration period of ground motion differs by location even in the same earthquake. Therefore, when studying reduction of building damage caused by earthquakes, we must not study earthquakes alone, but study earthquakes, subsurface structure, the ground, buildings and other relevant elements comprehensively.

In the 2008 Iwate-Miyagi Inland Earthquake and the 2009 earthquake in Suruga Bay, most stations recorded short period ground motion, but certain stations such as K-NET Hurukawa and K-NET Naruko exceptionally recorded slightly short period ground motion and long period ground motion (see Fig. 11). The result of surveys on the building damage caused by these two earthquakes is summarized in Table III. In the survey areas, neither of these earthquakes caused serious building damages such as complete or partial collapse other than damage to tiled roofs.

Outside the survey areas, however, there were a total of 176 buildings collapsed and 23 people dead or missing at the time of the 2008 Iwate-Miyagi Inland Earthquake. Furthermore, the Ichinoseki-nishi observation station in Iwate prefecture recorded the seismic acceleration 4,022 gal that was the largest in recorded history. Earthquakes with a maximum seismic intensity larger than 6-weak, which have been believed to cause complete or partial collapses of buildings, occur 1.3 times a year in average. In terms of damage rate, however, the damage is clearly smaller than assumed in most earthquakes. Rather, the 1995 South Hyogo Earthquake that caused serious building damage corresponding to the seismic intensity is regarded as an exceptional case. This indicates that building damage caused by earthquakes cannot be explained by the single indicator of seismic intensity.

5 Relations between Seismic Intensity and Building Damage

The current seismic intensity scale used by the Japan Meteorological Agency (JMA) is a ten-level scale that goes from 0 to 4, followed by 5-weak, 5-strong, 6-weak, 6-strong and then 7. It was an eight-level scale from 0 to 7 before 1996, but strong and weak levels were added to both seismic intensities of 5 and 6 after the 1995 Southern Hyogo Earthquake. This was because the damage situation varied widely by areas with the same seismic intensity.

Seismic intensity is not a definite physical quantity such as acceleration or amplitude. It is a complicated quantity related to many factors such as vibration period, amplitude, acceleration, and duration time. For that reason, it was determined by body sensory or damage situation until 1995. In recent years, numerical

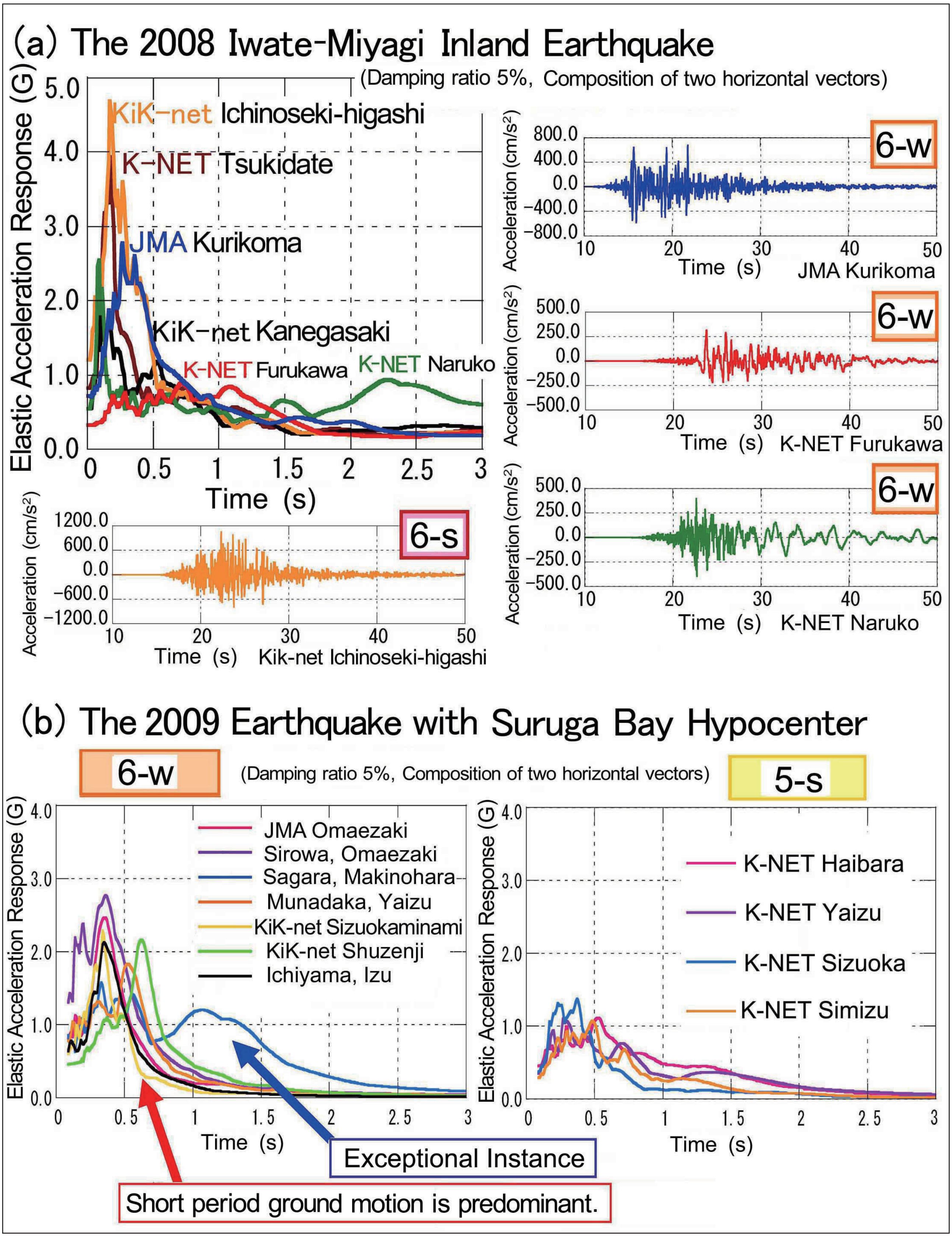

Figure 11 : The Elastic Acceleration Response Spectra in Two Major Earthquakes. (Provided by Y. Sakai)

Table III : Results of Surveys on Building Damage due to Two Earthquakes

(a) Building damage due to the 2008 Iwate-Miyagi Inland Earthquake

S.I.	Observation Station	S.I. Instr.	Damage Situation within 200 m Radius.	The number of buildings			
				All	Wood	Non-Wood	Col-lapse
6-s	Ichihasama,Kurihara (M),	6.2	Detached exterior materials, Block fence collapse, Roof tile damage, etc.	22	17	5	0
	Koromogawa, Oshu (I)	6.1	Exterior cracks in RC building, Roof tile damage, Ground damage, etc.	38	31	7	0
	KiK-net Ichinoseki-higashi (I)	6.0	Damage to public hall and gym exterior	4	4	0	0
6-w	JMA Kurikoma, Kurihara (M)	5.9	Small damage to exterior	14	13	1	0
	Uguisuzawa, kurihara (M)	5.8	Collapse of aged warehouse	40	32	8	0
	K-NET Tsukidate (M)	5.7	No Damage	53	47	6	0
	JMA Osaki (M)	5.6	Detached exterior materials	284	261	23	0
	Kannari, Kurihara (M)	5.6	Slanted warehouse, Detached exterior materials, Ground damage, etc.	26	14	12	0
	K-NET Furukawa (M)	5.5	Detached exterior materials, Broken glass windows, etc.	281	255	26	0
	K-NET Naruko (M)	5.5	No Damage	15	14	1	0
	KiK-net Kanegasaki (I)	5.5	Damaged block fence, Ground damage	12	11	1	0
	Tajiri, Osaki (M)	5.5	Detached exterior materials, Cracks in foundation of RC building, etc.	110	99	11	0
	Takashimizu, Kurihara (M)	5.5	Detached exterior materials, Other minor building damage	111	101	10	0
	Hanayama, Kurihara (M)	5.5	Detached exterior materials, Damaged block fence, etc.	38	30	8	0
	Shiwahime, Kurihara (M)	5.5	Exterior cracks in RC building, Detached exterior materials	57	43	6	0
	Isawa, Oshu (I)	5.5	No Damage	19	14	5	0
5-s	K-NET Ichinoseki (I)	5.0	No Damage	164	131	33	0

(I) Iwate Prefecture (M) Miyagi Prefecture

(b) Building damage due to the 2009 earthquake with Suruga Bay hypocenter

Observation Station	S.I. Instr.	Damage Situation within 200 m Radius	The number of buildings					Roof Tile Dmg. Rate (%)	Complete Collapse (%)
			Wood	Non-Wood	Complete Collapse	Partial Collapse	Roof Tile Damage		
JMA Omaezaki	5.7	Roof tile damage	131	7	0	0	6	4.8	0
Shirowa, Omaezaki	5.9	Roof tile damage to many buildings, Exterior damage	95	8	0	1	18	17.5	0
Sagara, Makinohara	5.9	Roof tile damage to many buildings	83	28	0	0	19	17.1	0
Sizunami, Makinohara	5.5	Roof tile damage to many buildings	154	33	0	0	17	9.1	0
Munadaka, Yaizu	5.6	Roof tile damage to many buildings	45	11	0	0	9	16.1	(0)
KiK-net Sizuokaminami	5.6	Roof tile damage, Interior damage to public swimming pool.	14	8	0	0	1	4.6	(0)
KiK-net Shuzenji	5.7	No Damage	1	0	0	0	0	0.0	(0)
Ichiyama, Izu	5.5	Roof tile damage	65	19	0	0	2	2.4	(0)
K-NET Haibara	5.4	Roof tile damage to many buildings	87	27	0	0	8	7.0	0
K-NET Yaizu	5.4	Roof tile damage	229	42	0	0	5	1.9	0
K-NET Shizuoka	5.1	Roof tile damage	334	214	0	0	1	0.2	0
K-NET Shimizu	5.2	No Damage	35	29	0	0	0	0.0	(0)

seismogram processing has been available, allowing for automated determinations by machines. This instrumental seismic intensity has been in use since 1996. For example, seismic intensity of 4 is defined by the automatically-determined values of 3.5 to 4.4, that of 5-weak by values of 4.5 to 4.9, that of 5-strong by values 5.0 to 5.4, and so on.

Automated determination of seismic intensity now allows TV and radio to report the seismic intensity at various locations within one or two minutes after an earthquake occurs. At present, only Japan has such a revolutionary system for prompt and detailed announcement of earthquake. In spite of the benefit from the system, a question arises as to whether the continuity between the former seismic intensity depending on body sensory and the current instrumental seismic intensity is well assessed or not. JMA documents say that the current instrumental seismic scale agrees well with the former scale up to the seismic intensity of 6 for earthquakes from 1988 to 1994. As yet, however, there has been no verification of consistency between the former and the current seismic scales for larger intensity than 6-strong after 1995. A possible inconsistency in seismic scales may cause the discrepancy between the current seismic intensity and percentage of building damage.

Since 1996, when the JMA adopted the instrumental seismic intensity, earthquakes with seismic intensities larger than 6-weak have increased in occurrence rate quite dramatically.[9,10] Figure 12 shows cumulated numbers of earthquakes with magnitude 6 and those with seismic intensities larger than 6-weak. In the

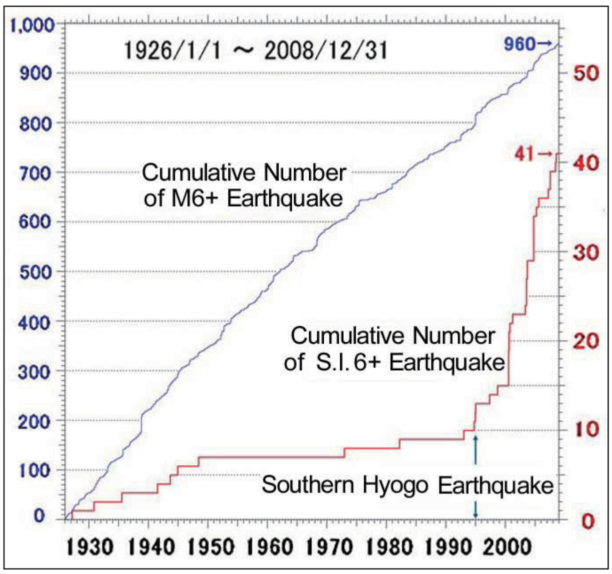

Figure 12 : Cumulative Number of Large Earthquakes. (Reprint from Ref. 10)

figure, we can see that the occurrence rate of large earthquakes has not changed, but that of earthquakes with seismic intensities larger than 6-weak increased abruptly by 15 times after 1996.

The increase in large-intensity earthquakes has been explained as a result of the increasing number of observation stations. It is because the network with many stations would not miss the area experiencing maximum seismic intensity. The explanation seems to be reasonable at first, but it is not obvious that it can explain a rate of occurrence that is 15 times higher. There is a possibility that a part of discrepancy in occurrence rate is caused by a difference between the current instrumental seismic scale and the former scale.

Yuki SAKAI proposed new indicator11 different from the instrumental seismic intensity, which will fit for the damage situation. The indicator is obtained by weighting the ground motions with certain vibration periods. If a clear discrepancy between seismic intensity and the damage situation frequently arises, the significance of the intensity as an indicator would be called into question. Certainly, there is an opinion that we should not change the current instrumental seismic intensity so lightly. If so, it may be a good idea to use another new index that would express structural damage of buildings.

Most ground motions have a short period of one second or less, and a slightly short period ground motion of one to two seconds does not necessarily occur often. Besides, the period of ground motion depends on both the ground structure and the propagation path of seismic waves. Because the shaking of the 2011 Tohoku Earthquake did not damage buildings seriously, many people may believe their houses not to be damaged by the ground motions with large seismic intensities such as 6-strong or 7. This is, however, a big misunderstanding, and it is quite dangerous for us to believe so. We should remind ourselves that an earthquake may cause enormous damages on buildings if it accompanies the large ground motion with a period of one to two seconds. The authors would like to stress that we should protect low- and medium-rise buildings against earthquake motions with a period of one to two seconds.

6 Super-high raise Buildings and Methods of Seismic Isolation and Vibration Damping

During the 2011 Tohoku Earthquake, a seismic intensity of 5-weak was recorded even in Tokyo distant from the hypocenter, and super-high rise buildings in the midtown swayed widely over a few minutes. Although the Japan Building Standards Act does not give a clear description of a super-high rise building, a building over 60 meters tall is often called a super-high rise building due to the prescription of Article 20, paragraph (1), in the act. The act requires that buildings taller than 60 meters must meet to quake-resistance standards by a certain analysis (time-history response analysis) using defined seismic waveforms.

The earthquake-resistant structure of buildings is classified roughly into three categories.

(a) Narrowly-defined earthquake-proof structure where the structure stiffness is increased for the purpose of enduring seismic force.

(b) Vibration damping structure where the motion of a building is suppressed by absorbing vibration energy.

(c) Seismic isolation structure where laminated rubber or sliding support prevent seismic force from reaching floors and upstairs.

Ordinary houses usually employ load-bearing walls or diagonal braces (i.e. narrowly-defined earthquake-proof structure) to enhance their earthquake safety, while super-high raise buildings employ vibration-damping and/or seismic-isolation structures. The own natural periods of low rise, high rise and super-high rise buildings are 0.5 seconds or less, 1 to 2 seconds, and 2 to 6 seconds, respectively. In general, the own natural period becomes longer for taller building. Consequently, a super-high rise building shows a large difference between the own natural period and the dominant period of ground motions, and thus the force and acceleration transmitted to the building become smaller (Fig. 13, left). Contrarily, the vibration amplitude and the building's deformation are increased in a super-high-rise building (Fig. 13, right).

In the vibration damping structure, seismic wave energy is absorbed by damper elements, which reduces both forces acting on the building and deformation of the building. Meanwhile, the seismic isolation structure reduces the forces transmitting to the building by prolonging the building's resonant period through the use of laminated rubber or spring dampers.

There are various types of vibration damping structures, but they are typically classified into the following three types.

(a) Inter-floor dampers: They prevent damage to a building by connecting the floor of the upper story to the ceiling (or the floor) of the lower story via dampers that can absorb vibration energy. Typical dampers are the oil damper and the low-yield steel damper as shown in Fig. 14.

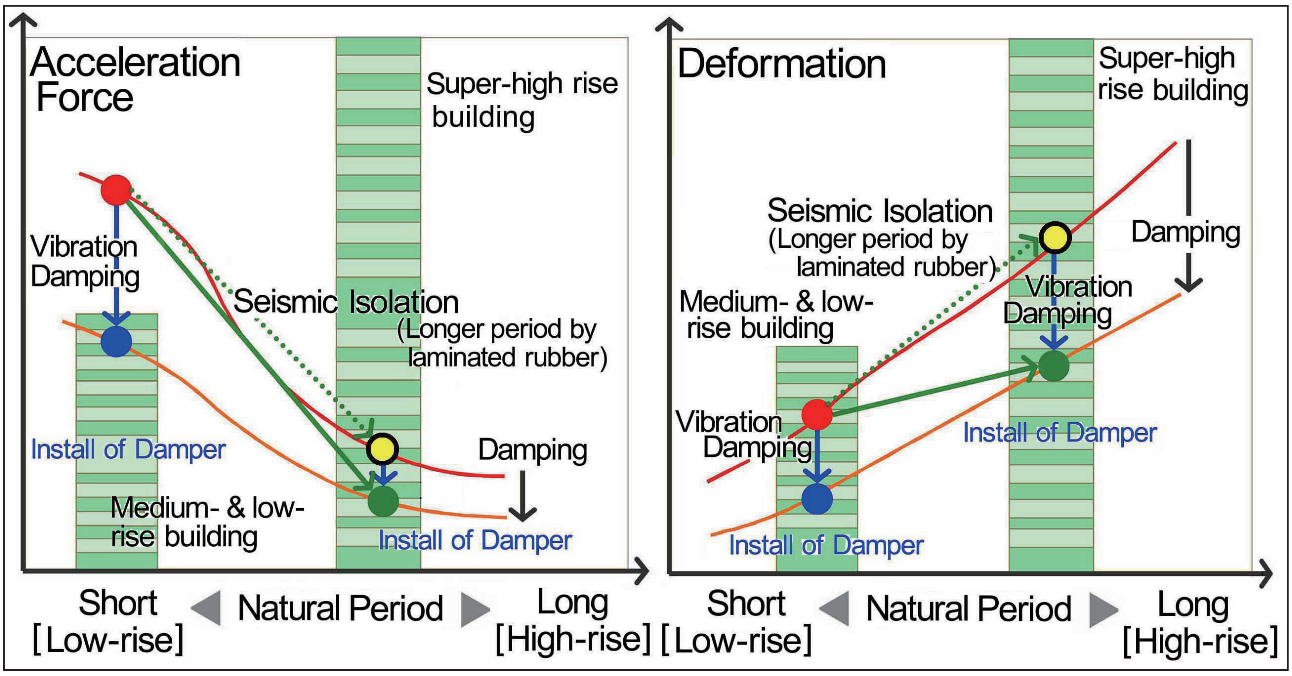

Figure 13 : Force Applied to Buildings and Deformation of Buildings. (Provided by S. Sakai)

Figure 14 : Types of Inter-Floor Dampers. (Provided by S. Sakai)

(b) Mass dampers: A "weight" is installed at the top of a building in order to suppress vibrations of the upper section of the building. In this case as well, the weight is connected to the building with dampers to absorb energy. In some cases, an actuator is used for the connection, providing active control by use of the force applied in the direction opposite to the sway of the building.

(c) Coupled vibration control structure: Separate structures (or separate buildings) with different natural periods are connected by dampers or bridge in order to suppress the vibrations. One example is the Harumi Island Triton Square where three buildings are connected by vibration control bridges. Another example is the Tokyo Skytree that has "Shin-Bashira," a central column of the tower, connected to the main body by oil dampers.

Differently from vibration damping, a seismic isolation structure prevents ground motions from transmitting to the building by installing laminated rubber or steel dampers on the foundation of building as shown in Fig. 15. The seismic isolation structure makes it harder for ground motions to enter the building by prolonging a natural period of the whole building including seismic isolation equipment (see Fig. 13). When the natural period becomes long, the force acting on interior portions of the building becomes smaller while the deformation of the building becomes larger.

The structure concentrates such deformation on the laminated rubber or steel dampers so as to prevent damage to the upper part of the building. However, we need to pay sufficient attention to wind pressure when installing a seismic isolation system in a super-high rise building because a strong wind may cause the sway of the building. Careful consideration should also be paid to the joint area around entrances or the building's surroundings, as the floor or the building itself may move differently from the ground.

Figure 15 : Structural Members of Seismic Isolation. (Provided by S. Sakai)

Figure 16 shows the seismic motion observed in a super-high rise building adopting a seismic isolation structure at the time of the 2011 Tohoku Earthquake. The earthquake-induced vibrations were measured on three different floors: on the foundation, the first floor and the twenty-first floor. Three different waveforms at the same floor indicate two horizontal motions and one vertical motion in order from top to down. In Fig. 16, we find that the horizontal motions of the first

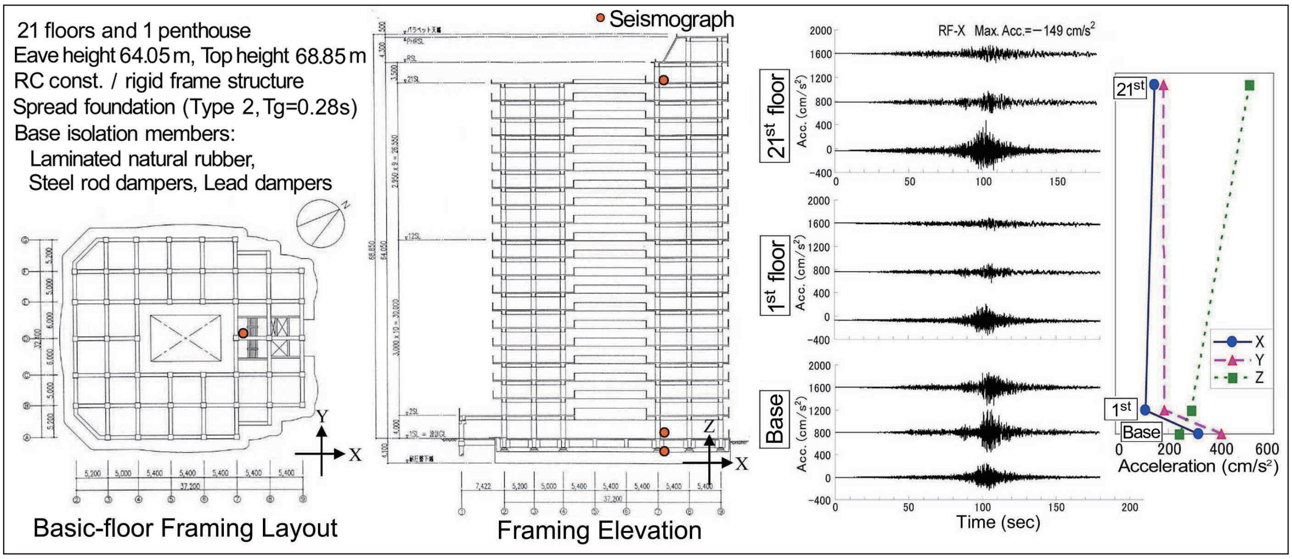

Figure 16 : Observed Motion of a Super-high Rise Building with Seismic Isolation during the 2011 Tohoku Earthquake. (Provided by S. Sakai)

floor are much smaller than those of the foundation. The acceleration of the first floor was about one-third of the seismic acceleration of the ground, which verified that the seismic isolation worked quite well. The vertical motion of the first floor, however, was not attenuated, and it turned out that the standard seismic isolation was not effective for vertical ground motion.

Since the earthquake-induced vibrations of the same building without a seismic-isolation cannot be measured, Shigeki Sakai and his colleagues just have to obtain them through computer simulation. The result showed that the seismic isolation structure reduced the vibration acceleration of the lower floors from 320 cm/s^2 to 100 cm/s^2, and that of the upper floors from 280 cm/s^2 to 160 cm/s^2.

The simulation also showed that the inter-story deflection angle, i.e. a relative story displacement divided by pillar length, would reach nearly 1/200 on many floors if the super-high raise building did not have the seismic isolation structure. In fact, the angle was 1/1000 or less on all floors thanks to the seismic isolation. When the angle reaches 1/200 or more, cracks supposedly start to develop in walls. Thus, it was confirmed that the seismic-isolation structure had a useful effect to protect a building against damage. Indeed, this building did not suffer any damages such as cracks in walls and pillar surfaces, nor furniture tipping accidents.

Both vibration-damping structure and seismic-isolation structure protect the whole building against damage by concentrating seismic force and deformation in dampers or laminated rubber. Hence, the strength and repetition tolerance of dampers or laminated rubber is a critical issue. After the 2011 Tohoku Earthquake, residual deformation in steel damper, cracks in lead damper, and loosened bolts were observed. Under such conditions, the effectiveness and reliability of vibration-damping or seismic-isolation largely decrease, and prompt repair or replacement may be necessary. Since these defects could be fatal particularly in the case of strong aftershocks, an emergency checkup should be conducted immediately after an earthquake. At present, we have neither methods of stress test against repeated vibrations nor evaluation standards for residual tolerance after an earthquake, which will be critical issues in the future.

The 2011 Tohoku Earthquake was the first case in which super-high rise buildings in the Tokyo metropolitan area swayed heavily for over 10 minutes. For instance, super-high rise buildings in Shinjuku experienced the swing up to 108 cm for 13 minutes. The scene has been video recorded and can be viewed on video websites. In the Tokyo metropolitan area, aftershocks accompanying “long period ground motion” were also observed. Figure 17 shows the ground motion observed in Shinjyuku at 3:59 a.m. on March 12. Though the acceleration of this aftershock is not large, the ground motion with a period of 5.6 seconds is clearly observed from 65 to 110 seconds in Fig. 17.

The long period ground motion got attention in Japan after an oil tank fire due to sloshing, a resonant phenomenon of fluid in a tank, at the Tomakomai industrial complex when the 2003 Off Tokachi Earthquake occurred. In the 2004 Niigata Prefecture

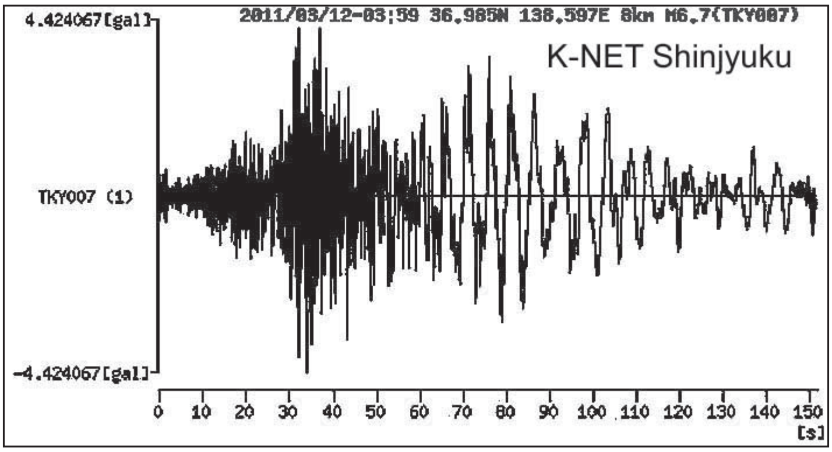

Figure 17 : Aftershock Ground Motion Observed at Shinjuku (from Ref.2)

Chuetsu Earthquake and the 2007 Niigata Prefecture Off-Chuetsu Earthquake, the long period ground motion damaged elevators of some super-high rise buildings in the Tokyo area. In addition, the oil tank fire that occurred in Niigata city at the time of the 1964 Niigata Earthquake was considered to have been caused by sloshing resulting from ground liquefaction, but today the cause is considered to have been the long period ground motion.

Modern super-high rise buildings in Japan, the first of which was the Kasumigaseki Building completed in 1967, had never experienced a large earthquake until the 2011 Tohoku Earthquake struck. Furthermore, many super-high rise buildings are located on the sedimentary ground layers such as Tokyo, Osaka, and Nagoya areas where the long period ground motion is commonly produced. The combination of a long period ground motion and super-high rise building is a largely unknown research region on earthquake damage. Based on this experience, we should address the critical issue of minimizing a possible damage caused by a future massive earthquake.

7 Summary and Conclusions

In this report, the authors want to draw out some lessons on disaster prevention from comparing building damages caused by two large earthquakes: the 2011 Tohoku Earthquake (the Great East Japan Earthquake) and the 1995 Southern Hyogo Prefecture Earthquake (the Great Hanshin-Awaji Earthquake).

The 2011 Tohoku Earthquake was a huge disastrous earthquake with large magnitude and large seismic intensities (6-weak and 7) over a wide area. Despite this, the ground motion did not cause serious damage to buildings differently from the 1995 Southern Hyogo Prefecture Earthquake. The reason is explained by the difference in the vibration period of the ground motion.

In the 2011 Tohoku Earthquake, “short period ground motions” with a period of one second or less were predominant, while “slightly short period ground motions” with a period of one to two seconds were rather quiet. The short period ground motion causes little structural damage like complete or partial collapses to buildings though people may experience it as a strong shaking. However, it causes damage to building walls and ceilings. Differently from the 2011 Tohoku Earthquake, the 1995 Southern Hyogo Prefecture Earthquake produced the slightly short period ground motion that seriously damaged many buildings.

Meanwhile, the 2011 Tohoku Earthquake and the aftershocks caused “long period ground motions” in Tokyo and swayed super-high rise buildings there. Seismic isolation and vibration damping devices worked well on a certain level, but their safety and effectiveness for the long period ground motion remain largely unknown. Hence, there are many issues to be studied in the future.

Slightly short period ground motion (with a period of one to two seconds) and long period ground motion (with a period longer than two seconds) cause quite different kinds of damages to different objects. The various causes dependent on vibration periods make the damage situation even more diverse than usual. It was just good luck in a sense that only little building damage was caused by ground motion in the 2011 Tohoku Earthquake. We need to note that a future earthquake with a similar level of seismic intensity may not necessarily cause the same degree of building damage. The disaster prevention plan for earthquakes based on predicted seismic intensity has only limited effectiveness and may serve as one of many guides. We must assume a situation where overall damage status cannot be fully identified by a single indicator of the JMA seismic intensity scale.

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References

[1] National Research Institute for Earth Science and Disaster Prevention: http://www.hinet.bosai.go.jp/about_earthquake/sec9.5.html

[2] K-NET and KiK-net (National Research Institute for Earth Science and Disaster Prevention): http://www.k-net.bosai.go.jp/k-net/gk/overview.html

[3] Rapid survey of building damage caused by the 2011 Off the Pacific Coast of Tohoku Earthquake; Damages to RC and steel-framed structures and to non-structural members in Nihonmatsu, Koriyama and Fukushima cities: http://www.nilim.go.jp/lab/bbg/saigai/h23tohoku/110314kentiku.pdf

[4] Rapid survey of building damage caused by the 2011 Off the Pacific Coast of Tohoku Earthquake; Damages to RC and steel-framed structures and to non-structural members in Shirakawa, Sukagawa and Sendai cities: http://www.nilim.go.jp/lab/bbg/saigai/h23tohoku/110324kentiku3.pdf

[5] "Ashiya city: Damage to buildings and restoration of them" (Ashiya city Website): http://www.city.ashiya.lg.jp/bousai/shinsai/bunseki.html

[6] "The Great Hanshin-Awaji Earthquake: Records in Ashiya city, 1995-1996" (Published by Ashiya city)

[7] Major disastrous earthquakes occurred in and around Japan (1996- 2011), Japan Meteorological Agency website: http://www.seisvol.kishou.go.jp/eq/higai/higai1996-new.html

[8] About the Great Hanshin-Awaji Earthquake (final report), May 19, 2006, Fire and Disaster Management Agency: http://www.fdma.go.jp/data/010604191452374961.pdf

[9] Y. Okada, "Three shocks in a day of earthquake occurrences with seismic intensity of 6"; Earthquake Journal, 36 (2003).

[10] Number of earthquakes with large seismic intensity and large magnitude, National Research Institute for Earth Science and Disaster Prevention website: http://www.hinet.bosai.go.jp/about_earthquake/sec1.3.html

[11] Y. Sakai, "The relationship between ground motion properties and building damage"; Bulletin of the Japan Association for Earthquake Engineering, 9 (2009) p12-19.

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