The Tokyo Electric Power Company, Inc. and NGK Insulators, Ltd. Inside Cooperative Innovation: Development and Commercialization of Sodium-Sulfur Batteries for Power Storage

Eishi Fukushima

IIR Case Study CASE#13-01

April 2013

Hitotsubashi University
Institute of Innovation Research

2-1 Naka, Kunitachi Tokyo 186-8603, JAPAN
http://www.iir.hit-u.ac.jp

Hitotsubashi University 21st Century COE Program
Dynamics of Knowledge, Corporate Systems and Innovation
Research Project on Okochi Prize Cases

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(Updated based on Japanese version written in 2008.)

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This case study is the result of research undertaken for the *Research Project on Okochi Prize Cases*, which is being conducted with financial support from the *Dynamics of Knowledge, Corporate Systems and Innovation* project under in the 21st Century COE Program at Hitotsubashi University. The project prepares case studies of research efforts that have been awarded the Okochi Prize that provide overviews of technical innovations and analyze the development process, the details and results of commercialization and related topics, in cooperation with the Okochi Memorial Foundation and firms that have received the award. Together with creating a portfolio of case studies and accumulating case data on Japan's major innovations, the project performs cross-comparative analyses of cases and seeks to identify the characteristics and issues surrounding innovation efforts at Japanese firms (for details refer to the following website (Japanese only): http://www.iir.hit-u.ac.jp/reserch/21COE.html). The author would like to express his deep appreciation for the extensive support and cooperation provided by the Okochi Memorial Foundation while pursuing this project.

Inquiries: Hitotsubashi University Institute of Innovation Research, Research Support Office
TEL: 042-580-8423 e-mail: chosa@iir.hit-u.ac.jp

Inside Cooperative Innovation: Development and Commercialization of Sodium-Sulfur Batteries for Power Storage[1]

Eishi Fukushima (Hosei University, Faculty of Business Administration)

1. Introduction

This paper examines the technology and business development process of the "sodium-sulfur battery for power storage" (referred to below as "the NAS battery")[2] created by The Tokyo Electric Power Company, Inc. (TEPCO) and NGK Insulators Ltd. (NGK). This innovation deserves deep consideration. As of 2007, the NAS battery is effectively the only high capacity battery for large-scale power storage that is being mass-produced and sold[3]. Although various firms in Japan, the U.S. and Europe undertook development efforts after the U.S. automaker Ford Motor Company announced the basic NAS battery principle in 1967, most of these projects ended in failure. Among the companies were TEPCO and NGK, which jointly pursued development and were the first in the world to commercialize NAS batteries. The two firms' NAS battery business launched its first products in 2002 and began mass production in 2003.

The TEPCO and NGK project to commercialize the NAS battery had the following characteristics. First, despite being the last to be formed, the development team was the world's first to achieve commercialization of the NAS battery. Almost no other examples of power storage battery commercialization on a mass production scale can be found. Second, it was a long-term project that required a period of about 20 years from the start of development to commercialization. Third, although a national project with a goal of developing a large-scale power storage battery was carried out during this period, neither TEPCO nor NGK participated in that effort. Various other entities took part in the

[1] The author received extensive support from individuals involved in research at The Tokyo Electric Power Company and NGK Insulators, Ltd. through interviews, presentations, and plant tours. The author would like to express sincere appreciation for this support. The author also wishes to express appreciation to the Okochi Memorial Foundation for its cooperation. Any errors or omissions in the text, however, are the sole responsibility of the author.

[2] "NAS" battery is a registered trademark of The Tokyo Electric Power Company, Inc. and NGK Insulators Ltd. As sodium-sulfur batteries use sodium (natrium or sodium) for the positive electrode and sulfur for the negative electrode, such batteries are typically referred to as NaS (Natrium-Sulfur) batteries after the initial letters of the materials. To avoid confusion, the mark "NAS battery" is used uniformly throughout this text.

[3] As we will see later, there are existing and potential competing technologies and products in the main markets for NAS battery use. These include systems such as superconducting magnetic energy storage, which have been sold to customers and installed for the purpose of verification tests, and some firms have seeking to move into commercial production since FY2007 (*Nikkei Sangyo Shimbun*, August 11, 2005). Although not being mass-produced and sold, there are other types of power storage systems, such as the pilot plant constructed under the Moon Light Project described below, or the lead-acid storage battery power storage systems that have been built in the U.S. and Germany (Nomura et al., 1993). Furthermore, according to the *Nikkei Sangyo Shimbun* in 2001, the UK electric power company Innogy (now npower, a subsidiary of the German company RWE, as of 2007) had plans to start operation of a power storage facility using Innogy's proprietary rechargeable "Regenesis" batteries as a commercial plant from 2002 and to sell the same plant overseas (*Nikkei Sangyo Shimbun*, August 29, 2001). Whether such plans have been executed could not be confirmed.

An "electric power facility system "verification test" (system field-evaluation) is a test by a supplier or specific user to assess the results of a system by operating a prototype product system under an actual application environment, and use the information obtained for future product development activities. The term "pilot plant" indicates the equipment setup for the verification test.

development of a battery for power storage under the “Moon Light Project,” which the former Agency of Industrial Science and Technology of the Ministry of International Trade and Industry (MITI) promoted in the 1980s. While this program achieved some results, no participants have reached commercialization. Fourth, rather than being an in-house development effort by one firm, the first half of the project was undertaken by three companies and the latter half was a joint development undertaken by TEPCO and NGK. The relationship between the two firms was basically as seller and buyer of the NAS battery, similar to their relationship for electric power-related materials such as insulators. While each company had their own objective, based on their relationship of the past and future transaction, they achieved commercialization through the joint development. Over the course of 20 years, the project faced various changes in its circumstances. As the project had progressed, conditions unique to each entity and the economic and social environment had also changed. Unlike other entities sought to realize practical applications of power storage batteries during this same period, the TEPCO-NGK project did not enjoy central government support for the development. Why, and in what manner, was the NAS battery commercialization pursued by TEPCO and NGK? In the following, we examine the background and historical process of their venture, and then discuss why their commercialization became possible in the last section.

2. Background of Development

2-1. Alternatives to electric-load leveling and pumped-storage power generation

The NAS battery first attracted attention as a means to level electric power loads in place of pumped-storage power plants, and the development started in this vein. Behind this push were the fact that capacity factors of power generating facility had declined whilst maximum electric power demand was growing, and that pumped-storage power generation faced some restrictions concerning location, cost, power loss and construction period.

The beginning of NAS battery development by various firms was the discovery and announcement of the fundamental principle in 1967 by Ford Motor Company[4]. Ford’s announcement was related to the basic principle for a new type of battery that used sodium and sulfur, plus “β-alumina.” β-alumina is a ceramic that until then had been considered a fireproofing material, as the electrolyte. This new battery, which later came to be called the NAS battery, was characterized by its ability to achieve 4-5 times greater energy density compared with conventional lead acid storage batteries. Following Ford’s discovery, NAS battery development was pursued actively in the 1970s, mainly in Japan, the U.S. and Europe. One major reason the NAS battery garnered attention was the fact that at that time, the only practical means power utilities had to store the large amounts of power they generated was “pumped-storage power generation.”

Generally speaking, an electric power utility is required to prepare power supply capacity to meet the maximum demand during its peak periods rather than an average of demand (over one year or one day, for example). For example, even if the peaking time is short and the peak demand differs greatly from the average demand, supply capacity

[4] Yao and Kummer (1967), Weber and Kummer (1967), and Kummer and Weber (1968).

needs to meet the maximum demand. The reason is that if demand cannot be met, even for a short period, power outage occurs, which will cause extensive losses to both individuals and organizations. A stable supply of electric power is therefore demanded from a social and public viewpoint, and ensuring its product does not “run out of stock” is considered to be one critical mission of every electric utility. Given such circumstances, power utilities will maintain facilities for power generation that add 8-10% reserve power generation capacity to maximum demand, to respond to uncertain demand fluctuations. As a result, to the extent the difference between the maximum demand (and reserve) and average demand increases, a power generating facility’s average capacity factor will decline, as shown by its annual load factor[5].

Such difference is not necessarily resulted from special conditions. It is well known that the volume of electric power demanded typically varies greatly between the daytime and nighttime time bands. During the day, when most people are active, electric and electronic equipment use is many times greater than during the night when people are asleep, and on the whole more electricity is needed. In addition, to the extent people increase their electric and electronic equipment use, the quantity of electricity demand based on each individual’s activity will grow. If use of electric devices increases, average power increases as well, while the difference between peak demand and average demand widens. The result is that when offices increase their use of telecommunications equipment, factories introduce industrial robots in conjunction with industrial development and households run home appliances such as air conditioners, the difference between peak demand and average demand will widen, as power generating facilities are built to meet growing peak demand[6]. If a power generating facility’s average capacity utilization rate falls, the cost of power supply rises. To provide for maximum power demand, power utilities must boost investment in plant and equipment, and consumers must purchase expensive electricity.

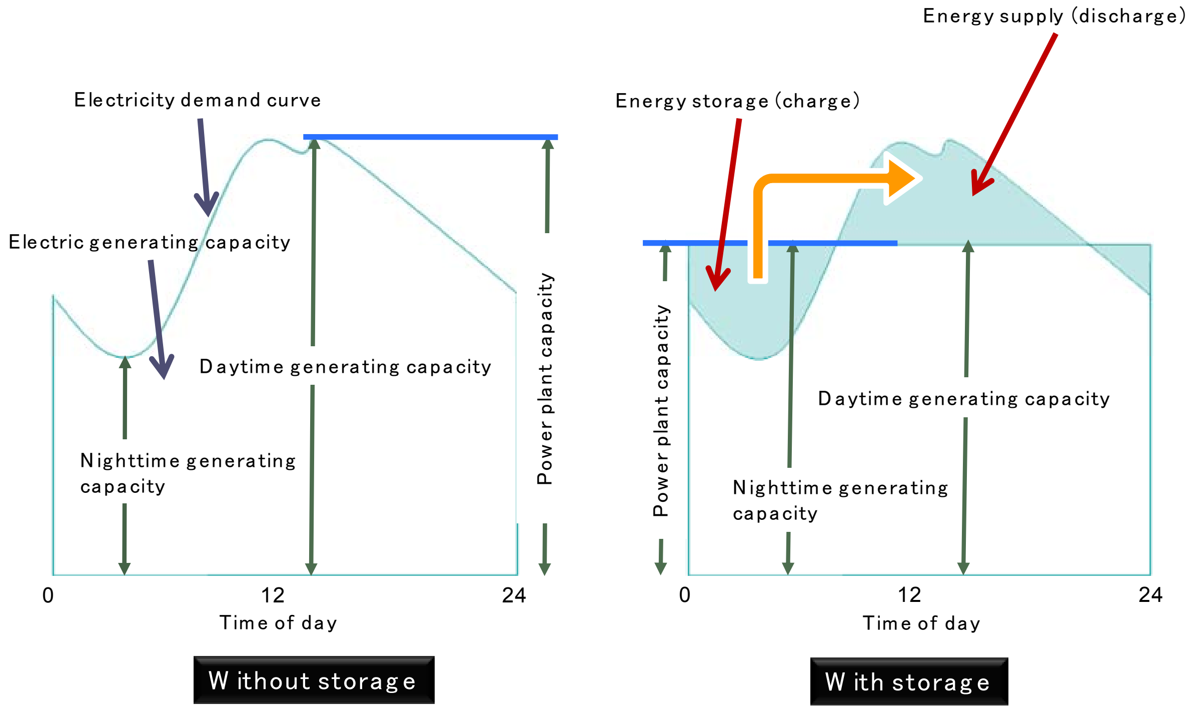
To cope with such conditions, one effective approach is to hold electric power (on the power sending side or receiving side) in a “storehouse” – that is, to store electricity. If electric power generated during time bands when power demand is low can be stored, and the stored electricity released during time bands when electric power demand is high, the peak demand for which a power company must prepare will be leveled toward the average demand volume, as shown in Figure 1. This approach is referred to as electric power “load leveling.”

The traditional method used as a means to store electricity to meet load leveling needs is pumped-storage power generation. Pumped-storage is a type of hydroelectric power generation using two reservoirs constructed at different elevations. Nighttime surplus electricity is used to pump water to the upper reservoir, which is then discharged into the lower reservoir to generate electricity by spinning turbines with water pressure during the daytime when electricity demand is high. This cycle is repeated. In other words, electric

[5] Annual load factor is the percentage (%) calculated by dividing average power per day for a one-year period by the peak demand in the same year. For the peak demand value, utilities normally use the average electric power for the three-day period during the year that required maximum electric power.
[6] Fluctuations in electric power demand include not only changes depending on the time of day but seasonal ups and downs as well, such as the demand surges during summer when numerous air conditioners are operating.

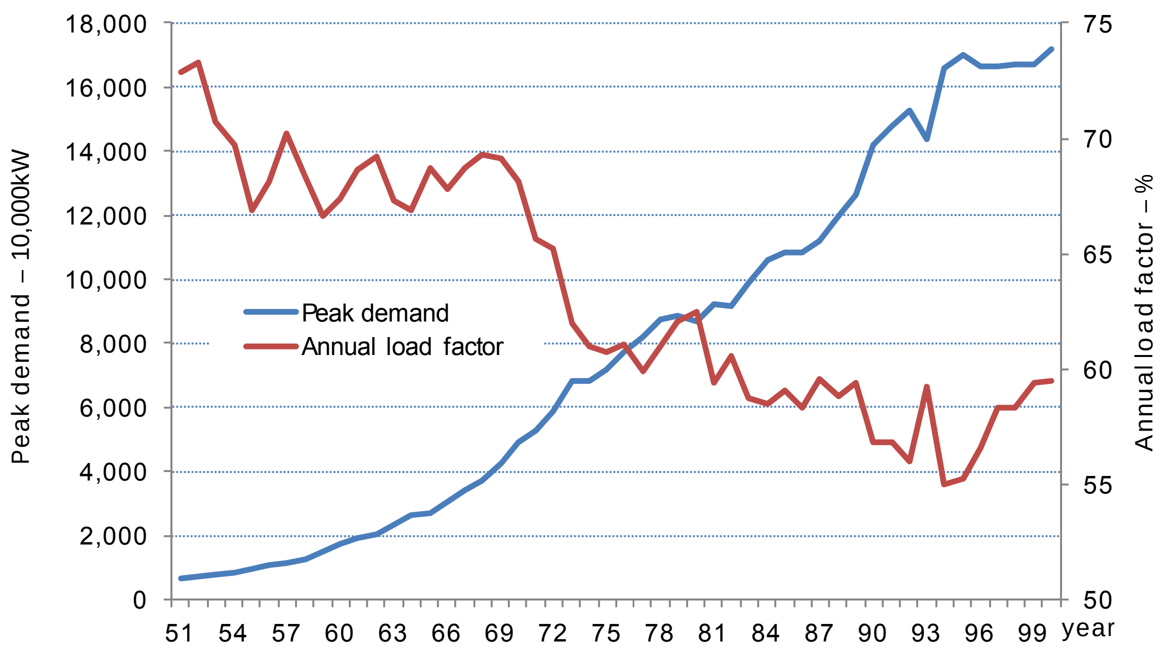
power is stored as “potential energy of water.”

Figure 1. Electric power load leveling conceptual diagram



Source: Prepared by referring to Isozaki et al. (1998).

Figure 2. Change in peak demand and annual load factor



Source) Prepared by referring to Japan Business History Institute (2004).

Electric power load leveling has been used in Japan through pumped-storage power generation facility construction. However, as peak demand has been rising annually, the annual load factor for electricity has exhibited a long-term downward trend, as shown in

Figure 2. When the total and average values for nine Japanese general electric utilities shown in the graph are examined (excluding Okinawa Electric Power Company, Inc.), peak demand has expanded greatly from 6.67 million kilowatts (abbreviated below as kW)[7] in 1951 to 92.45 million kW 30 years later in 1981. The average annual growth rate during this interval was 9.16%. In contrast, during the same period the annual load factor has decreased from 72.9% to 59.4%.

An alternative means of electricity storage was sought because, in addition to the rise in peak demand and the declining trend in the annual load factor, pumped-storage power generation was considered to have the following problems[8]. First, for technical reasons the locations of pumped-storage power plants are limited to remote mountain areas, and it was thought that appropriate locations for such facilities within Japan would decrease[9]. Second, the construction of pumped-storage power plants, power transmission lines and other facilities is extremely expensive. Power plant construction costs alone are substantial, and when a power plant is built deep in the mountains, a long transmission line to the areas where the electric power is consumed must be built. To save electricity through pumped-storage power generation, the construction cost was estimated as 300,000 yen per 1kW at that time. Third, there is a commensurate loss of power. As the distance of power transmission increases, the transmission of electricity is accompanied by a loss of electric power, and changing the form of electric power into the potential energy of water causes a further loss through the process of reconverting this into electricity. As a power supply, the charge and discharge efficiency was estimated at 65-70%[10]. Fourth, from the viewpoint of nature conservation, the submersion of a broad expanse of ravine area for construction of a pumped-storage power plant cannot always be considered desirable. Finally, because building a pumped-storage power plant can take about ten years from start of construction to completion, there is a potential for discrepancies to arise between the load leveling plan and actual requirements.

As we will see below, during the 20 years until the NAS battery was commercialized by TEPCO and NGK the circumstances described above changed, and these changes influenced the battery commercialization project. Behind the push by these two firms and many other companies to develop the NAS battery, however, was the consistent social need to search for an alternative means of storing electricity to replace pumped-storage for the purpose of load leveling. After confirming that electric power storage technology that might provide an alternative to pumped-storage was not limited to the NAS battery, let us examine the NAS battery characteristics, which led TEPCO and NGK to focus on the development of the battery.

2-2. Alternative technologies for electricity storage

The development of new batteries including the NAS battery was sought as a means to

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[7] Kilowatt shows the unit for electric power. One kilowatt is equal to 1,000 watts.
[8] There is an opinion to include another reason for the need of electric power storage. It points out a difficulty for nuclear power generation to generate power in accordance with load, thus, its low flexibility to adjust electricity generating capacity (Nikkei Sangyo Shimbun, October 29, 1981).
[9] As an attempt to overcome such locational limitations, R&D on seawater pumped-storage power generation that uses the ocean for the lower reservoir is also being conducted (Tanaka, 1995).
[10] Nikkei Sangyo Shimbun (April 3, 1987).

replace pumped-storage because of the lower loss of electric power compared to other means of storing electricity, and the possibility of installing them close to the demand due to their small size. In addition, compared with traditional lead acid storage batteries, those new batteries had high theoretical values for electricity storage capacity per unit. They were expected to provide an alternative to pumped-storage from the standpoints of economic efficiency and durability.

Electric power storage technologies to replace pumped-storage power generation are broadly of two types. One is batteries that store electricity by converting electric energy to chemical energy, such as lead acid storage batteries, which is proven but old technology, and NAS batteries. Other type is technologies similar to pumped-storage power generation that convert energy into other forms for energy. Typical examples of the latter technologies, that convert energy into another form and store electricity, include flywheels, compressed air energy storage (CAES) and superconducting magnetic energy storage (SMES)[11].

The flywheel is an energy-storage technology whose principle has been long understood. Surplus electricity is used to spin a disk, and when power is needed again, this rotating force is used to generate electricity. The electrical energy is stored by converting it into the kinetic energy of the rotation. Some have been put to practical use for short-term storage of small amounts of electricity, such as uninterruptible power systems and supplemental electric power for trains. As for longer-term high-power storage, R&D efforts have been undertaken to combine superconducting technology with flywheel in recent years[12]. CAES involves using surplus electricity to compress air that is stored in bedrock; when power is needed, electricity is generated by recovering the compressed air and using it to burn natural gas to spin a gas turbine. The first practical applications using rock salt strata with hardness suitable for storing compressed air were introduced in Germany at the end of the 1970s and in the United States in 1991. In Japan, having no rock salt strata, R&D activity with various adaptations has been conducted using abandoned mines[13]. SMES is a technology to store electricity as magnetic energy, using superconductive coils whose electrical resistance is eliminated when the coils' temperature is lowered to some extent. A "dream technology" with no theoretical loss of electric power, this technique allows high-quality, large-scale electricity storage to be anticipated. For this reason, power utilities, electric machinery and electric wire manufacturers and other entities have conducted vigorous R&D activities since the 1980s, when the high-temperature superconducting phenomenon was discovered, despite the enormous scale of the equipment and the economic and technical difficulties of the devices[14]. Verification tests with an eye on commercialization have been performed in recent years at several facilities, including a liquid crystal panel manufacturing plant[15].

All of the electricity storage technologies described above are technologies to store

[11] Superconductivity is also sometimes referred to as "superconductive wiring" (Iwanami Shoten, *Koujien* Fifth Edition, 1998).
[12] Nikkei Sangyo Shimbun (July 26, 1983) and Nihon Keizai Shimbun (June 15, 2005).
[13] Nikkei Sangyo Shimbun (August 29, 1991; March 5, 1992; December 28, 1995).
[14] In 1986 the Research Association of Superconducting Magnetic Energy Storage was formed by 49 companies (Nikkei Sangyo Shimbun, December 27, 1995).
[15] Nihon Keizai Shimbun (August 9, 2005) and Nikkei Sangyo Shimbun (July 27, 2007).

electric power by converting it into forms of energy other than chemical energy. While the anticipated times required until practical application and the development challenges of these respective technologies vary, they all share the characteristic that energy is lost by conversion of the power during input and output. Because the emphasis of the TEPCO and NGK project was placed on the electricity charge and discharge efficiency of the power storage device, devices that might experience a large conversion loss were eliminated from the development options considered[16]. Moreover, despite the strong possibility for technologies such as CAES and SMES to provide large amounts of power from a single device, there is a high probability of power loss through transmission. Because the equipment fundamentally is large-scale, it is difficult to locate near the site of electric power demand, just as in the case of pumped-storage power generation. In both the TEPCO/NGK project and programs under the Moon Light Project, the focus was on batteries small enough to install in the vicinity of demand, such as substations, under the development objective of an alternative to pumped-storage[17].

Table 1. Key characteristics of batteries considered applicable for electricity storage

Item/battery	Sodium sulfur	Zinc chlorine	Zinc bromine	Redox flow	Lead acid storage battery
Theoretical energy density (Wh/kg)	780	828	428	103	167
Open circuit voltage (V)	2.1	2.1	1.8	1.0	2.1
Reactant	Na (liquid)/S (liquid)	Zn (solid)/Cl2 (gas)	Zn (solid)/Br2 (liquid)	Cr2+ (liquid)/Fe3+3 (liquid)	Pb (solid)/PbO2 (solid)
Reactant utilization	85%	100%	100%	80-90%	30%
Electrolyte	Solid electrolyte (β-alumina)	ZnCl2 solution	ZnBr2 solution (KCL added)	HCl solution	H2SO4 solution
Operating temperature	300～350°C	20～50°C	20～50°C	60～80°C	5～50°C
Circulation system	Not required	Required	Required	Required	Not required

Source) From Ozawa (1983), p. 14; partially revised.

On the other hand, firms and government identified some sort of large-scale batteries to be developed in the early 1980s, at the time when TEPCO and NGK began their project. Those new batteries, shown in Table 1, were targeted for development as an alternative to lead acid storage batteries. Those include the NAS battery, zinc chlorine batteries, zinc bromide batteries and redox flow batteries. Let us take a look briefly at the characteristics of four rechargeable batteries that might provide alternative technologies to the NAS battery.

Lead acid storage batteries have been used over many years from the 19th century right up to the present. They have long been known as an existing technology that in

[16] Although this point hints at the technological development issues for reducing the losses accompanying conversion to a level that will support practical use, this was not what decided the absolute superiority or inferiority of the technologies and their selection based on a comparison. There are a number of companies including power utilities that are conducting R&D activities into both storage technologies that involve conversion of the energy form, such as SMES, and the rechargeable batteries discussed below.

[17] The “Advanced Battery Energy Storage System” program under the Moon Light Project was an effort to develop an “urban-type power supply of the future” which is capable of distributing installation near sites of demand like urban areas, maintaining the same functions as pumped-storage-type hydroelectric power” (Nikkei Sangyo Shimbun, January 19, 1982: February 16, 1983).

principle might be used for large-scale electricity storage. A lead acid storage battery uses lead dioxide and spongy lead for the plates and diluted sulfuric acid for the electrolytic solution. It discharges electricity when the sulfuric acid in the electrolytic solution is transferred to the plates, and charges when the sulfuric acid is transferred from the plates into the electrolytic solution. Lead acid storage batteries have found widespread use, because they can be manufactured cheaply for the main material is lead, and because they do not ignite easily and very safe. However, the electricity storage capacity per volume is low. Accordingly, to ensure large capacity needed to store electric power generated at a power plant, large number of individual batteries would have to be connected and an extensive installation area would be needed. Such an arrangement is inferior to pumped-storage power generation from a cost perspective[18]. It has also been pointed out that when lead acid storage batteries are used for large-scale electricity storage, they have a short lifespan of about 2.7 years, i.e. a problem with durability[19].

In addition to providing an alternative to pumped-storage power generation, the new batteries viewed as development candidates at that time were expected to possess characteristics not easily achieved by existing lead acid storage batteries. That is, besides offering economy and safety, they were expected to provide greater electricity storage capacity per volume plus excellent durability.

As their name indicates, zinc chlorine batteries use zinc and chlorine for their plates and a zinc chloride solution for the electrolyte[20]. These devices function as a battery by generating chlorine through electrolysis when charging, and the chlorine being absorbed when electricity is discharged. The theoretical energy density per weight of these batteries is 828Wh[21] per kilogram. This energy density is the highest among the four new rechargeable batteries discussed here[22]. In addition to high energy density, zinc chlorine batteries have some other benefits. They have high-quality electricity due to small voltage fluctuations during charging and discharging, and ability to withstand high output power and high loads. Low material costs are another benefit, although the chlorine generated when charging requires safety measures. However, because electricity is stored using liquids known as hydrates, energy efficiency is greatly reduced and external storage tanks are required[23]. Like the zinc bromide batteries and redox flow batteries we

18 Nikkei Sangyo Shimbun (July18, 1989; July 17, 1991; January 16, 1992). The cost per kW of electricity of normal or improved lead acid batteries was well above the pumped-storage power generation cost of 200,000-300,000 yen, although the former varied from 500,000 yen to 1.5 million yen depending on articles, and thus its date of issue (Nihon Keizai Shimbun, February 28, 1983; Kikkei Sangyo Shimbun, September 27, 1985; June 18, 1988). The charge and discharge efficiency of such batteries in these articles also varied from 67% to 87% (Nikkei Sangyo Shimbun, July 25, 1983; June 18, 1988; November 8, 1989).

19 Nikkei Sangyo Shimbun (March 11, 1999).

20 For technical explanation of these batteries, see Agency for Natural Resources and Energy (1995), Nihon Keizai Shimbun (February 28, 1983 and December 5, 1989), Nikkei Sangyo Shimbun (May 10, 1983; July 12, 1983; July 25, 1983; April 23, 1984; April 18, 1986; November 30, 1990; January 13, 2000; November 2, 2003), and the ULVAC Corporate Center Ltd. (2005).

21 The electric power unit is shown in “watts”. For example, 828Wh indicates a battery can output 828 watts of electricity for one hour, or one watt of electricity for 828 hours.

22 Each value for the theoretical energy density per volume of the four types of batteries differed depending on the proponent. In this paper, theoretical energy density per weight, that was adopted in press releases and so forth, was used as a measure. Every value for the measure here were described originally in Ozawa (1983) of the Ministry of International Trade and Industry’s Electrotechnical Laboratory (at that time).

23 Nikkei Sangyo Shimbun (May 10, 1983; January 14, 1986; July 22, 1986). With development of the

will look at below, these batteries charge and discharge by circulating electrolytic solution.

Zinc bromine batteries use zinc and bromine for the plates and a zinc bromide solution for the electrolytic solution. The electrolytic solution is circulated by a pump between the battery tank and two tanks isolated by a microporous membrane that selectively passes bromine ions. The batteries use the electrical charge and discharge properties generated by causing the bromine zinc solution to react chemically. At 428Wh per kilogram, this battery's theoretical energy density per weight ranks third among the four new rechargeable batteries. The zinc bromine battery's benefits are a high degree of safety because they operate at normal temperatures and do not require temperature control devices. They also have another benefit that inexpensive plastic can be used for the container and electrode plate materials. However, safety precautions are necessary for the bromine, and devices such as pumps to circulate the electrolytic solution must be installed.

Redox flow batteries are batteries that charge and discharge electricity using two types of redox solution (chrome ions and iron ions), partitioned by an ion-exchange membrane, as electrolytic solutions; electrons are exchanged between the two solutions[24]. Their structure is divided into an electrolytic cell where an electrochemical reaction occurs between carbon fiber electrodes and a tank from which redox solutions are supplied to the electrolytic cell. Redox flow batteries charges and discharges by circulating these solutions with a pump. Electricity output can be increased if the electrolytic cell is enlarged, and an electric current can be generated for an extended period if the tank's capacity (electrolytic solutions volume) is expanded. Benefits include the ability to increase capacity for long-term use, simple safety management due to the normal temperatures operation, and long life with little chemical change inside the battery. However, the battery's theoretical energy density per weight is 103Wh per kilogram, the lowest among the four new rechargeable batteries. There is also a tendency for batteries to grow in size like chemical plants, because they need to circulate large amounts of electrolytic solution as capacity is enlarged.

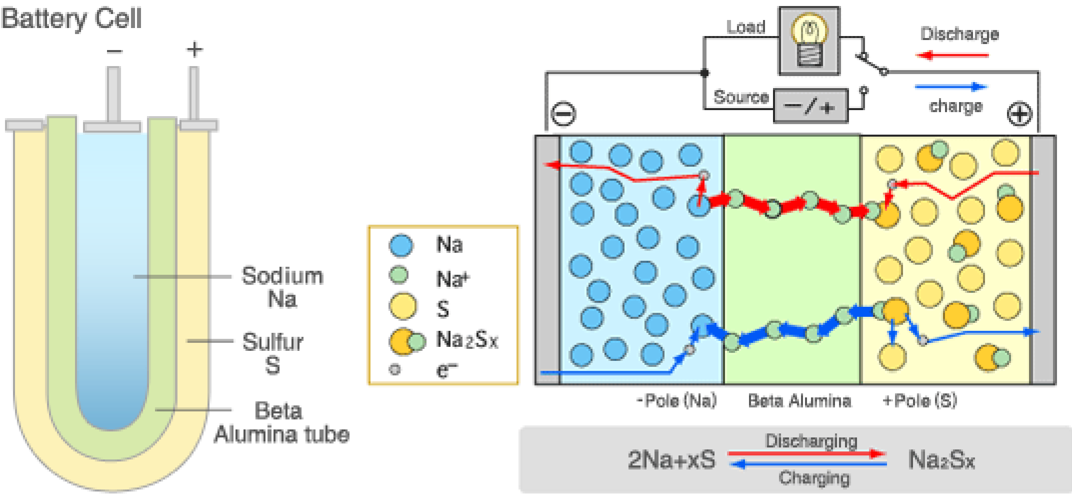
2-3. The NAS battery as the target for development

Among new batteries, TEPCO and NGK chose NAS battery as a target for development. Decisive factors behind their choice were NAS battery's technical properties. NAS battery has high theoretical energy density, and no need for moving parts such as pumps. However, considering enormous technical difficulties to overcome, the prospect for commercialization of NAS battery was not necessarily promising as with other new batteries.

"solvent method" to replace the traditional "hydrate method," energy efficiency was later improved more than 70%.

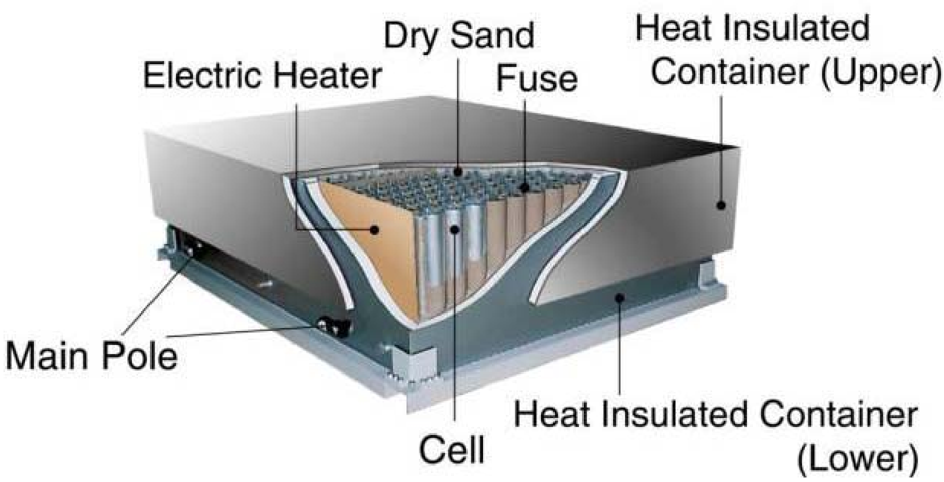
[24] The size of the batteries was reduced and the output power of them was enhanced later, using a sulfuric acid aqueous solution, yielding vanadium ions in, as the electrolytic solution (Nikkei Sangyo Shimbun, December 5, 1996; January 13, 2000).

Figure 3. NAS battery structure and operating principle



Source) Taken from NGK website
(http://www.ngk.co.jp/english/products/power/nas/principle/index.html).

Figure 4. Structure of an NAS module battery



Source) Taken from NGK (2005), p. 7.

The heart of an NAS battery is the electric cell shown in Figure 3[25]. Sodium is used for the negative pole, sulfur is used for the positive pole and an ion-conducting ceramic called "beta alumina" is used for the electrolyte. To form the structure, sodium is placed inside a tube made of beta alumina (β alumina) and sulfur is placed around the outside of the tube, and these components are enclosed entirely within a metallic cylinder. When the electric cell is heated to about 300° centigrade, the β alumina will pass sodium ions. During discharge, the negative pole sodium is changed into ions, passes through the β alumina and reacts with the positive pole sulfur to form sodium polysulfide. During charging, the sodium polysulfide in the positive pole breaks down and the sodium ions return to the negative pole. Because the electromotive force of the electric cell is low and

[25] The technical explanation of the NAS battery provided here is based on TEPCO & NGK (2004; 2006).

the capacity for electricity storage also is small, to operate a storage system multiple electric cells are combined in module batteries like the one shown in Figure 4. Because the operating temperature is about 300°C, module batteries are set inside insulated containers equipped with electric heaters used to raise the battery temperature. Because of the adiabatic characteristics of the containers, which are hermetically sealed, heat insulation is highly effective and the heaters are used mainly when starting operations.

The first strength of the NAS battery is its high theoretical energy density, which is roughly 4-5 times that of lead acid storage batteries. If the theoretical energy density per unit area is large, batteries can be installed in comparatively small spaces[26]. Second, because pumps, valves and other movable parts to circulate the electrolytic solution in other new rechargeable batteries are unnecessary, ease of battery maintenance is a big plus. Moreover, in contrast to the liquids adopted as an electrolyte for the other new batteries, because solid β alumina was adopted, self-discharge is not a problem, and it appears possible for NAS batteries to achieve high charge and discharge efficiency. In addition, as with other dry batteries, the battery structure is completely sealed, and unlike other new batteries no gas is generated. Finally, mass-production and low-cost supply can be anticipated because the sodium and sulfur used as materials are readily available resources and expensive materials are unnecessary.

Like other rechargeable batteries, however, NAS batteries have some characteristics that are also considered to be drawbacks. First, heaters are needed as an accessory because the batteries must be operated at 300°C to improve conductivity of the β alumina ions and break down the sodium polysulfide. Second, the sodium and sulfur materials are highly chemically active. Third, because it is a type of ceramic, the β alumina solid electrolyte cracks easily. Under the high operating temperature of about 300°C, the β alumina can be damaged easily because it is under various thermal and mechanical stresses; this is dangerous because the sulfur will react directly with the sodium if the electric cells are damaged[27]. This meant that elaborate security measures were necessary. In fact, as we'll see later, the frequent occurrence of fires experienced as a result of β alumina damage led many entities to abandon NAS battery development.

The issues that had to be overcome to achieve practical application of the NAS battery presented a high degree of technical difficulty. For this reason, at the beginning of the development project in the early 1980s, the battery's absolute dominance over other new batteries was not assured. The difficulty of confirming the absolute technological superiority or inferiority at that time can be identified from the fact the development of all four new batteries in parallel was encouraged under the government's Moon Light Project.

2-4. NAS battery development entities

Development of these new batteries including the NAS battery gathered steam during the 1970s, primarily in Japan, the U.S. and Europe, with support from each country's government. The main applications envisaged for new battery development were

[26] In a comparison of per unit volume, the theoretical energy density was said to be four times that of lead acid storage batteries (Nikkei Sangyo Shimbun, February 10, 1986).
[27] Nikkei Sangyo Shimbun (December 16, 1989).

electricity load leveling (as an alternative to pumped-storage power generation) and electric vehicles (as an alternative to the internal combustion gasoline engine).

In the United States, companies such as Ford Motor Company, General Electric (GE) and Dow Chemical were tackling NAS battery development for electric power load leveling and electric vehicles under the auspices of national projects implemented by institutions such as the Department of Energy (DOE)[28]. These development activities by U.S. firms were discontinued in the 1980s, however. Although Ford, the NAS battery pioneer, was achieving high-level development results at that time, together with the other two companies it withdrew from this battery development in the latter half of the 1980s owing to cutbacks in government support[29].

Because the electric power load factor was relatively high in Europe, NAS battery development there was undertaken mainly for electric vehicles[30]. In Europe the two firms that had pursued NAS battery development the most energetically were Chloride Silent Power Limited (CSPL)[31] in Britain and Brown Boveri & Cie (BBC)[32] in Germany. Both companies continued development pursuits until the late 1990s with government support in Germany, the U.K. and the United States, achieving commensurate progress[33]. They withdrew from NAS battery development, however. In the UK, government financial support was cut as part of the liberalization of the electricity business and CSPL was purchased by RWE of Germany. BBC withdrew from NAS battery development when BBC rationalized its business portfolio following the formation of ABB[34]. The transfer of BBC's development results to NGK through Nastech Corporation, a joint-venture established with ABB, however, had a significant influence on the progress of the TEPCO and NGK project.

Development of new batteries including the NAS battery was encouraged in Japan as well from the 1970s through two national projects. These were the Large-scale Project for Electric Vehicle Research and Development in the first half of the 1970s, which

[28] The DOE promoted the development of new batteries for electricity load leveling and electric cars from the 1970s under its national Research Project for Electrochemistry Energy Storage, and in the 1980s encouraged verification tests of these batteries in cooperation with the Electric Power Research Institute (EPRI) (Nakahara, 1983; Nikkei Sangyo Shimbun, May 10, 1983).

[29] Futamata and Takahashi (1986). However, Ford and GE's development results were probably succeeded to by Chloride Silent Power Limited (CSPL) in the U.K. Ford had set up Beta Power, Inc. jointly with Ceramatec, which was supplying Ford with β alumina tubes, to carry out development of NAS batteries for electric power load leveling. Later, Beta Power was acquired by CSPL. In 1980, GE also moved to a joint development with CSPL.

[30] Iwabuchi and Kimura (1980), Nakahara (1983).

[31] CSLP became a subsidiary of Germany's RWE in 1992 and was renamed SPL (Silent Power Limited).

[32] BBC merged with the Swedish heavy electric machinery firm Asea in 1988, and the new entity was renamed ABB (Asea Brown Boveri). Depending on the time period, the names BBC and ABB were used.

[33] CSPL pursued development of an NAS battery for automobiles with funding support from the ECRC (Electricity Council Research Center), an agency of the British government. From 1985, CSPL undertook development on consignment of an NAS battery for electric power storage under the ETD (Exploratory Battery Technology Development and Testing) Project and the Sodium Sulfur Battery Engineering for Stationary Energy Storage Program) implemented by the U.S. Department of Energy (Koenig and Rasmussen, 1996; Braithwaite and Koenig, 1993). In addition, BBC pushed into NAS battery development with support from the West German federal government, and in 1992 announced a business plan to start mass production (Nihon Keizai Shimbun, June 20, 1991; June 13, 1992). This plan, however, was never realized.

[34] Hamer (1996).

encouraged the development of electric vehicles and power supplies[35], and the Moon Light Project from the late 1970s to promote development of energy-saving technologies, including electricity storage batteries. These two projects, which the government pursued by outsourcing development to multiple firms, achieved respective results in the form of test runs of electric vehicles, and verification testing of a 1,000kW-class pilot plant. But the participating firms were unable to turn the results into viable businesses.

Four types of new battery including the NAS battery, and three types of improved lead rechargeable batteries, were developed through the large-scale electric vehicle project, which was carried out between fiscal 1971 and 1976[36], and Yuasa Battery took charge of NAS battery development[37]. Maintenance problems and stabilization of oil prices, in addition to the technical difficulties, were major obstacles to practical application of the electric vehicles and batteries developed by these projects[38].

Subsequently, the Advanced Battery Energy Storage System development project was carried out under the Moon Light Project between fiscal 1980 and 1991. The project was formed to pave the way for future replacement of pumped-storage power generation with new batteries installed at substations in urban neighborhoods. Four types of batteries – the NAS battery, the redox flow battery, the zinc chlorine battery and the zinc bromine battery – were selected for development[39]. The objective to be reached was a “practical level” that provided energy efficiency and economic efficiency equivalent to or greater than pumped-storage power generation, with a ten-year useful life. The effort was undertaken with Yuasa Battery handling NAS battery development, NGK Spark Plug providing the β alumina tubes and Kansai Electric Power Co., Inc. providing the verification test locations. Although verification tests of a 1,000kW-class plant were conducted for the NAS batteries and zinc bromine batteries[40], economic efficiency, durability and safety issues remained as problems to be solved. Because it was recognized that a significant amount of time would be required until practical application to be realized, the electric power industry was requested to take over the research efforts[41].

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[35] In addition to Yuasa Battery, a participant in this project that had begun pure research in 1968, basic research was carried out separately from this project at Toyota Central R&D Labs., Inc. and Japan Storage Battery Co., Ltd. (Chiku et al.,1975; Iwabuchi and Kimura, 1980). Furthermore, large-scale production of β alumina was attempted at NGK Spark Plug Co., Ltd. in the 1970s (Nikkei Sangyo Shimbun, October 3, 1978).

[36] The three types of improved lead rechargeable batteries were, respectively, the multi-layer positive electrode-type, porous film electrode-type and circular thin multi-layer structure lead battery. The new batteries that became the subject of development were batteries with a theoretical energy density higher than lead acid storage batteries and which could be produced using inexpensive materials. In addition to the NAS battery, new battery types targeted for development were the solid electrolyte-type and circulating electrolyte-type zinc-air battery, the iron-air battery and the iron-nickel battery (Agency of Industrial Science and Technology, 1974; Ishikawa, 1998).

[37] Yuasa Battery Co., Ltd. changed its company name to Yuasa Corporation in 1992; it merged with Japan Storage Battery Co., Ltd. in 2004, and adopted its current name of GS Yuasa Corporation in 2007. To avoid confusion it is referred to below as Yuasa Battery.

[38] Ishikawa (1998). The maintenance problems were caused by the fact that the new batteries other than the NAS battery were not sealed and had open casings. However, several thousand electric vehicles that used conventional lead acid storage batteries were supplied for factories, delivery use, etc. (Nikkei Sangyo Shimbun, May 7, 1993).

[39] New Energy and Industrial Technology Development Organization (1992), Ohashi (1987), Nihon Keizai Shimbun (September 19, 1983).

[40] Nikkei Sangyo Shimbun (June 14, 1989), Nihon Keizai Shimbun (May 22, 1987).

[41] Nikkei Sangyo Shimbun (March 9, 1992; April 3, 1992; May 11, 1992). The joint research by the

Soon afterward, Distributed-type Battery Energy Storage Technology Development project under the government's New Sunshine Program (the name of the comprehensive technology development promotion plan for the energy and environmental sectors) was carried out in the 1990s[42]. In place of NAS batteries, this project focused on developing lithium-ion batteries as next-generation batteries for household electric-load leveling and electric vehicles.

As TEPCO and NGK had undertaken development of NAS battery independently of the Moon Light Project, they remained active to develop the battery even after the Advanced Battery Energy Storage System program had ended in the 1990s[43]. While CSPL and ABB continued development in Europe and the U.S., and the Japanese electric power industry also took over the Moon Light Project' research, both efforts had virtually ended by the mid-1990s. Even Yuasa Battery, which had pushed NAS battery development through the two national projects and had continued vigorous activity announcing a mass production plan[44], turned its focus to lithium ion batteries in the New Sunshine Program[45].

In addition to each company's unique circumstances, the following have been cited as reasons why many firms have found it difficult to maintain NAS battery development[46]. First, firms found it difficult to expect they could lower the product introduction cost to a level that would encourage product acceptance. Second, it was expected to require more time to ensure NAS battery safety, for the product was susceptible to fire accidents caused by vibrations or impacts. In other words, from the standpoints of economic efficiency, durability, and safety, firms believed practical application would take time. With such circumstances as a backdrop, it is little wonder firms thought it difficult to continue development over an extended period in the face of cutbacks in government assistance, adjustments to resource allocations in conjunction with changes in operating results, and the appearance of promising alternative technologies.

3. Development and Practical Application of the NAS Battery by TEPCO and NGK[47]

As development activity stretched out over time, difficulties many of the firms working

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electric power industry continued from 1992 to 1995.

[42] New Energy and Industrial Technology Development Organization and the National Institute of Advanced Industrial Science and Technology (2002), and Nikkei Sangyo Shimbun (April 7, 1992; December 18, 1992; May 9, 1996).

[43] Redox flow battery development also was continued for many years, not by Mitsui Engineering & Shipbuilding Co., Ltd., which took charge of this under the Moon Light Project, but by a joint research entity of Kansai Electric Power Co., Inc. and Sumitomo Electric Industries, Ltd. Kansai Electric Power and Sumitomo Electric Industries had elected to develop a battery on their own, apart from the national project (Tokuda, 1995).

[44] Iwabuchi and Kimura (1980) and Nikkei Sangyo Shimbun (October 1, 1985; March 18, 1986; November 17, 1989).

[45] Yuasa Battery's withdrawal from NAS battery development and commercialization could not be confirmed clearly. Following the end of the Advanced Battery Energy Storage System project under the Moon Light Project, there have been few articles touching on the company's NAS battery development. According to the Nikkei Sangyo Shimbun (February 29, 2000), however, as of 2000 the company was developing a hybrid power supply system combining NAS batteries with wind and solar power generation for uses such as emergency power supply and nighttime lighting. Therefore, NAS battery development can be thought to have been continued in some form at this company, even if on a reduced scale, until at least 2000.

[46] Nikkei Sangyo Shimbun (July17, 1991; September 30, 1994; August 29, 2001).

[47] The description in this section is based mainly on the following sources: TEPCO and NGK (2006) and interviews by the author at both companies (February 9, 2007; February 21, 2007), and Nakabayashi Takashi (2004a; 2004b).

on the NAS battery confronted, influenced the continuation of development efforts. Despite encountering difficulties, however, the TEPCO-NGK project reinforced its development organization over a 20-year period, continued development, and finally commercialized the technology. Let us examine the NAS battery business development process the two companies experienced.

3-1. Beginnings of the project

NAS battery development drew TEPCO's attention because of its consistent needs as an electric power utility to find a means of storing electricity in place of pumped-storage power generation. Driving the search were the various restrictions on pumped-storage power generation and rapidly growing electricity demand. Looking at the effort needed until practical application of the technology, it was thought the electric utilities themselves, rather than the government, ought to shoulder the development. While Hitachi, Ltd. was chosen as a development partner because of its strong desire to develop the batteries and its ample resource capacity, cooperation with a manufacturer possessing strengths in ceramics technology was considered essential. Ceramics manufacturers rejected the request for cooperation, however, owing to the NAS battery's technical difficulties. The reason NGK finally accepted TEPCO's request for cooperation was that NGK thought the relationship it had cultivated with TEPCO in electric power materials over many years might help NGK diversify its business. NGK foresaw the approaching maturation of its core insulator business, and decided it should try to pursue diversification into new businesses.

The TEPCO and NGK project was launched at the beginning of the 1980s. The project got its start when TEPCO decided, in 1982, to aim at NAS battery commercialization separately from the Moon Light Project. Although participation in the Moon Light Project also was contemplated by the company[48], ultimately it undertook development on its own in cooperation with manufacturers[49].

The primary reason NAS battery development was initiated at TEPCO was the expectation that the company would, like the Moon Light Project, be able to achieve a means of storing electricity to replace pumped-storage power plants. For an electric utility, having an alternative to pumped-storage power generation as a means of storing electricity was recognized as a clear need from the viewpoint of controlling capital investment and reducing costs. The number of pumped-storage power facilities cannot be increased easily because of location restrictions and the investment amount required. Besides, because of their geographic distance from the area of demand, such facilities were viewed as a source of power transmission loss. In addition, the early 1980s when the project was initiated was a period when electricity demand was rising rapidly, and this had stimulated the desire to develop an alternative means of storage. Yoshiharu Tachibana[50], who was involved in the project at TEPCO from the earliest stage as chief

[48] Nikkei Sangyo Shimbun (April 2, 1982; February 10, 1986).

[49] On the other hand, TEPCO participated in the High Performance Gas Turbine Development Project that was carried out from fiscal 1978 through fiscal 1987 under the Moon Light Project.

[50] A TEPCO Fellow as of February 2007. Until June 2006 he was Executive Officer and Director of the Research and Development Center subsequently. The following quotes are taken from the interview records (February 9, 2007).

researcher and later became director of the Electricity Storage Division and head of the Research and Development Center subsequently, commented on this point as follows.

> For electric utilities, the desire to develop batteries as a means of electricity storage had long been a definite business necessity. It was wanted continuously for many, many years. What kicked us off then was the situation around the pumped-storage power generation. You may be familiar with this technology. Electric utilities have a means of electricity storage in the form of pumped-storage power station. For this technology, we have to find a mountainous location appropriate for pumping water up from a lower reservoir to a higher one. When we started our project many forecasted that the utilities would probably not be able to build as many pumped-storage power stations as needed. That forecast actually turned out to be wrong, but we only learned that later. At the time of the commencement of the project, the forecast was all that serious. On top of that, it was the time when electricity demand was growing rapidly. These two combined factors formed an absolute desire to find some method to store electricity that could replace pumped-storage power generation. This was a kind of challenging situation we faced[51].

The main reason why an independent development organization was formed separately from the government project was a thought that it was not just for an elemental technology development but also for the future practical application. Electricity utilities had to, therefore, undertake development and establish the technology by themselves[52]. Such opinions, championed at the time by TEPCO president Gaishi Hiraiwa and the top management, strongly supported the project continuously. Tachibana described this as follows[53].

> I heard that, given that we absolutely had to succeed the project because this technology was so extremely important, the top management at that time had judged that the batteries would never be successfully developed if we – that is, the electric power utilities – didn't develop the technology by ourselves. . . . And looking back on what transpired afterwards, I appreciate that we always had a strong support of the top management, especially from Mr. Hiraiwa… who I recall was president at the time we began. He later became chairman, and is now acting as a company executive advisor. To my mind, that consistent support of the top management, championed by Mr. Hiraiwa, was surely the greatest resource that enabled us to continue the project[54].

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51 Quoted from the interview record (February 9, 2007).

52 According to the article on Nikkei Sangyo Shimbun (February10, 1986), practical application was expected by the "first half of the 1990s" at that time.

53 Hiraiwa was TEPCO's president from 1976 until 1984 and chairman until 1993, after which he served as an advisor until 2007. TEPCO's presidents after Hiraiwa were Sho Nasu (1984-1993), Hiroshi Araki (1993-1999), Nobuya Minami (1999-2002), and current president Tsunehisa Katsumata (2002-2007).

54 Quoted from the interview record (February 9, 2007). An omission was made by the author.

The project begun by management instruction went through alternative technology evaluation and NAS battery selection in 1982, then moved to the development partner selection phase. TEPCO's basic stance at that time on technology development activities was to identify a cooperating manufacturer, split the development funding and undertake joint development. Hitachi, Ltd. was selected as the battery manufacturing partner. TEPCO selected the manufacturing partner that had not lost its development ardor even after the passage of 18 years since the announcement of the NAS battery principle by Ford and also had not joined the government's project. There were only a few manufacturers which could meet the criteria. Because Hitachi was an eminent heavy electric machinery company, Hitachi's resource capacity was also considered reliable. As a result, an NAS battery development team was formed at the Hitachi plant that was responsible for nuclear power generation facilities at Hitachi. Since the division of Hitachi was already responsible for fast breeder reactor research, it was accustomed to working with the sodium raw material. And since it had a comparatively large R&D budget, it was considered capable of handling development risk. Joint development of the NAS battery was begun by TEPCO and Hitachi in 1983.

Despite having begun joint development with Hitachi, TEPCO continued to search for a ceramics manufacturer as a development partner. The reason for the search was given by TEPCO vice president Kazuo Fujimori. He argued that collaboration with a specialized producer of ceramics was essential for development because the NAS battery would use ceramic for the electrolyte. Consequently NGK and several other manufacturers were asked to cooperate, but every firm replied that it could not cooperate. All of the companies gave as their reason the substantial development risk stemming from the NAS battery's technical difficulties. In fact, NGK had surveyed the feasibility of NAS battery commercialization in 1979, independent of the joint development proposal from TEPCO. Its conclusion at that time was that practical application would be difficult.

NGK, which had expressed disapproval, was persuaded eventually to begin the joint development project by following events and reasoning. The first was a visit by Managing Director Tsuneo Mitsui, head of TEPCO's Research and Development Center, who called on Noboru Yamamoto, an Executive Director and manager of NGK's Research and Development Laboratory and fervently explained the project[55]. The fact that TEPCO was an important customer for NGK's electricity business, especially insulators, and that the two firms had built a relationship of mutual trust and knowledge sharing based on long-term transactions, was implied in this episode.

Second, as NGK considered participation in the project, it surveyed the state of the technology of NAS batteries, particularly at European and U.S. firms to reevaluate the

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According to this interview, because the Moon Light Project was a framework under which "the government requested development directly from manufacturers and power utilities provided the locations for verification tests," firms could not participate in the project if they were not asked by the government.

[55] In 1986 TEPCO's Mitsui held the position of Managing Director, Executive General Manager of the Engineering R&D Division, where he led TEPCO's technology development activities until being appointed Senior Executive Advisor in 1991. Noboru Yamamoto, NGK Executive Director serving concurrently as Director of Research and Development Laboratory, became the first president of Nastech Corporation, the NAS battery joint venture with ABB, in 1987. In the following year he assumed the position of Technical Advisor to NGK Insulators Ltd.

feasibility of practical application. After receiving the joint development proposal from TEPCO, Kokuji Kito, General Manager of the engineering department in the Power Business Group, was sent to Europe and the U.S. to investigate the state of the technology first-hand. The results of this survey were part of the materials that led to NGK's participation in the project.

Finally, the fact that NGK was eager at the time to diversify through the development of new businesses greatly influenced its judgment. Initially NGK participated in the project as the development entity for the β alumina tubes, a key NAS battery component. As we will see later, however, in 1987 NGK formed a technical tie-up on NAS batteries with ABB, and in the following year established Nastech, a joint venture with ABB, to conduct NAS battery R&D. In other words, within three years from their participation, NGK decided it would participate not as a parts supplier but as a "battery manufacturer."

According to Masaharu Shibata, NGK's president from 1994 to 2002, NGK foresaw the maturation of the insulator business, its mainstay since the 1950s, and had adopted "transformation through diversification" as the company credo[56]. Sooner or later, the high-voltage lines that used NGK's insulators would reach every corner of Japan, and given insulators' excellent durability, replacement demand was expected to be minimal. NGK has since expanded into ceramics materials for automobiles such as vehicle exhaust emissions and filters, piezoelectric ceramics for printers, incineration plants, materials for semiconductor fabrication devices, and materials for mobile phones like SAW filters and beryllium copper connectors. While the policy of diversification through new business development and a relatively large R&D investment to pursue this goal sometime run up against NGK's reorganization of its businesses[57], it has been followed by successive generations of NGK managers. Toshihito Kohara, who was NGK's president from 1986 to 1994, set an objective of generating one-third of net sales through new businesses by 1996[58]. Shunichi Takemi, who gave the go-ahead for participation in the NAS battery project and was NGK president from 1977 to 1986, is also known for his aggressive diversification of NGK into areas such as materials for automobiles and commercialization of incinerators for sewerage treatment facilities. Takemi commented on NGK's diversification and the development of the NAS battery business as follows.

> I again realized the extent of the effect of "increased management efficiency through new business development" from the fact that establishing our HONEYCERAM[59] business for automobiles had enabled us to absorb surplus employees whose jobs were eliminated by the withdrawal from unprofitable divisions. For me as well, encouraging development, especially development in the markets and technical fields we specialize in, was a major issue during my tenure as president. Looking back, I think the fact we began R&D on the sodium-sulfur (NAS) battery for electricity storage was a smart decision. . . . Given the amount of time required for development, the sizable

[56] Based on an interview with Shibata published in the Nikkei Sangyo Shimbun (December 18, 2001).
[57] Nikkei Sangyo Shimbun (September 28, 1993).
[58] Nihon Keizai Shimbun (January 27, 1986).
[59] HONEYCERAM is NGK's ceramic catalyst carrier product for exhaust gas purification.

> cost and the human resources we invested, there were some hesitant voices. However, it was a promising future business, and I decided that if we could also win TEPCO's support based on the trust we had earned from the electric power industry in the electricity market, where NGK is strong, we had the potential to handle the R&D. . . . The NAS battery had seen ten years of development. And practical application was not so far away. Now you might be tempted to say, 'What, ten years and still no product?' But in NGK, many products have a long development period, and in most instances even when we do R&D, we have to entrust commercialization to the next generation. As a managerial judgment, deciding on the R&D priority is quite difficult and requires courage. I don't think it's any easier to judge just because someone has come up through a technical field[60].

The 1980s when the project was initiated was also a period when NGK had decided to zealously pursue diversification[61]. The NAS battery was positioned within the flow of new business development for diversification with the backdrop of proposals from key customers in NGK's main business.

3-2. Joint development by the three companies

Two NAS batteries were made by Hitachi through the collaborative project among TEPCO, Hitachi and NGK. One used β alumina tubes made by Hitachi, and the other used NGK's. TEPCO set the battery development goals and evaluated the batteries' performance. The project development goals were set based on the assumption the batteries would replace pumped-storage power generation and be installed near the source of electricity demand. In particular, effort was poured into enhancing β alumina tube durability, a problem many development entities struggled with. The development teams at Hitachi and NGK held contrasting approaches to manufacture.

The NAS battery project begun by the two firms in 1983 became a joint development organization among the three companies in the following year when "development and joint research on solid electrolyte tubes" was started by TEPCO and NGK in 1984. This was the final group formed as the NAS battery development entity. At TEPCO, the three engineers led by Tachibana, the chief researcher at the Engineering R&D Division's R&D Center, were given responsibility for the NAS battery project in a form that left them concurrently handling other development themes. At NGK Takashi Isozaki, general manager of the R&D department in the Research and Development Laboratory, had responsibility for the project and led eight experts in materials research, ceramics and performance evaluation. General Manager of the Research and Development Laboratory was Yamamoto at that time.

The joint development entity by the three companies started in the following form. TEPCO set development goals and specifications, along with verifying field performance

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60 Quoted from Takemi's *My Personal History*, published in the Nihon Keizai Shimbun (June 22, 1994).

61 According to the Nihon Keizai Shimbun (February 8, 1985), before NGK began the project with TEPCO in 1984, a "New Business Sector Study Team" was organized under Noboru Yamamoto, Executive Director and manager of the Research and Development Laboratory. The mission given to the team was to "search for new revenue sources."

at the substations and having overall control of the research. However, two development lines were outlined and the project moved forward in the form of a competition between the two lines. For the first line, Hitachi made both the battery and the β alumina tube components that comprised the batteries. For the second line NGK made the β alumina tubes and Hitachi used these to produce the batteries. TEPCO assessed the results of the two lines.

Like the new battery development under the Moon Light Project, the aim of the project initially was to install the batteries at demand locations as an "alternative to pumped-storage." As shown in Table 2, the development objectives were (a) realize a 1,500 electrical charge/discharge cycle corresponding to durability of ten years, (b) reduce the power generation cost to 300,000 yen per kW (equivalent to that of pumped-storage power generation) and (c) ensure compact size and safety. However, during the 1980s, the focus was mainly on overcoming the durability issue[62], because NAS batteries were "expected to suffer damage to the β alumina when electrical charging and discharging was repeated over only several hundred cycles at most, and there were difficulties to improve durability".

Table 2. TEPCO-NGK NAS battery development objectives

Item	Objective
Durability	At least 1,500 cycles (10 years)
Energy efficiency	At least 75% (electrical charge and discharge every 8 hours – AC end)
Economic efficiency	Equivalent to or exceeding pumped-storage power stations
Compact size	Small enough to install in cramped spaces in Tokyo metropolitan area (at least 70kWh/m^3; at least 175kWh/m^2)
Safety	Damage doesn't expand at times of external, internal irregularities

Source) Prepared by referring to Okuno (1993) and Harada (1993).

Since Ceramatech, Inc. in the U.S. was selling the highest quality β alumina tubes in 1984, NGK sought to achieve performance equivalent to this product. The team first began by studying the characteristics of β alumina, and worked to clarify the mechanism that damaged the material. It also undertook research on technology that could address this issue thoroughly, even going so far as to investigate the composition of the raw material powder.

To improve the β alumina tubes, NGK's know-how related to the manufacture of ceramic products including insulators was used. NGK improved the β alumina tube performance through countless cycles of creating and destroying prototypes, then creating and destroying them again, until "there was a mountain of defective products in the backyard." Since ceramics products tend to exhibit variations in performance, and products for electric utility require high level of stability and quality not to lead disastrous accidents, optimization through such an empirical approach was considered to be essential. Hitachi's approach to NAS battery development, on the other hand, could be said to have been a contrast to NGK's. For nuclear reactors, making and destroying

[62] Okuno (1993).

prototypes like insulators wasn't suitable. Optimization is achieved based on exhaustingly repeated computer analysis, and a nuclear reactor is built just once, based on the results. As the NAS battery development team was part of the nuclear power division at Hitachi, the development was undertaken using a method similar to the approach for nuclear reactors.

3-3. The establishment of Nastech and changes to the development organization

NGK's proposal to develop the main body of the battery itself modified the project's organization so the two NAS batteries made by Hitachi and NGK would compete on performance. In a step that clarified it would diversify into the electricity storage battery business, NGK formed Nastech, a jointly managed NAS battery R&D firm, with the German company BBC. At NGK, top engineers of the organization were brought onto the NAS battery development team, and the size of the team was expanded. Technology exchange with BBC of Germany through Nastech improved NAS battery performance significantly, and it was decided to take the project to the next phase. In 1992, a 50kW-class system was completed as a "practical prototype installation," and subsequently the project worked on enlarging the system. Hitachi exited the project in the next year, and continued the development of its own independently.

In 1989 the joint development organization came to change when TEPCO and NGK's "development and joint research on solid electrolyte tubes" ended. In the same year, NGK proposed to TEPCO to begin "development and joint research on electric cells" while implementing "module battery and related control technology development" on a parallel track. TEPCO accepted this proposal, and decided on a policy that both Hitachi and NGK producing β alumina tubes and batteries and pitting their results against each other[63]. The proposal from NGK and the development organization change were meant to highlight the fact that NGK was not just a vendor of ceramics components in the form of β alumina tubes and that it intended to diversify into the electricity storage battery business as a battery manufacturer. Besides, the technical interdependency between the β alumina tubes and batteries can be said to have been another factor behind NGK's proposal. When the β alumina tubes suffered damage during operation, it was also necessary to study the battery structure in order to determine the cause. To perform this investigation smoothly, carrying out the study internally is more desirable than a division of labor between firms.

The groundwork for NGK's entry into the battery business through the NAS battery is thought to have actually been laid from several years prior to this period, however. For starters, in 1986, two years after participation in the project, three engineers from Yuasa Battery and other battery manufacturers were invited to join NGK. The purpose was to introduce know-how from technical and business perspectives on batteries, with which the company until that time was unfamiliar. This was followed by the technical tie-up for NAS batteries with BBC of Germany in 1987[64]. In 1988, this technical tie-up evolved into

[63] According to the Nikkei Sangyo Shimbun (28 August, 1989; January 6, 1990), the battery development group for the project had already been divided between NGK and Hitachi in August 1989, and the 10kW system evaluation at TEPCO in March 1990 targeted the units developed respectively by these two companies.

[64] Isozaki et al. (1998).

the establishment by NGK and BBC of the jointly managed R&D firm Nastech, which had a major impact on the success of the project.

Although NGK had produced NAS batteries experimentally before it entered the technical tie-up with BBC, it was not thought to have a sufficient level of technology to proceed to actual manufacturing and commercialization of a product. This was the reason it decided, after surveying NAS battery R&D conditions overseas, to form the technical alliance with BBC, which possessed state-of-the-art technology. The technical tie-up and establishment of Nastech were undertaken to introduce NGK's functional ceramics materials technology into BBC and bring BBC's NAS battery manufacturing technology into NGK[65]. NGK took a 60% stake in Nastech for 320 million yen[66]. Despite the agreement with BBC confined NGK's sales rights for NAS batteries to Far East[67], the technology exchange through Nastech resulted in enormous improvement to NGK's battery processing technology and enabled the project to make great strides forward.

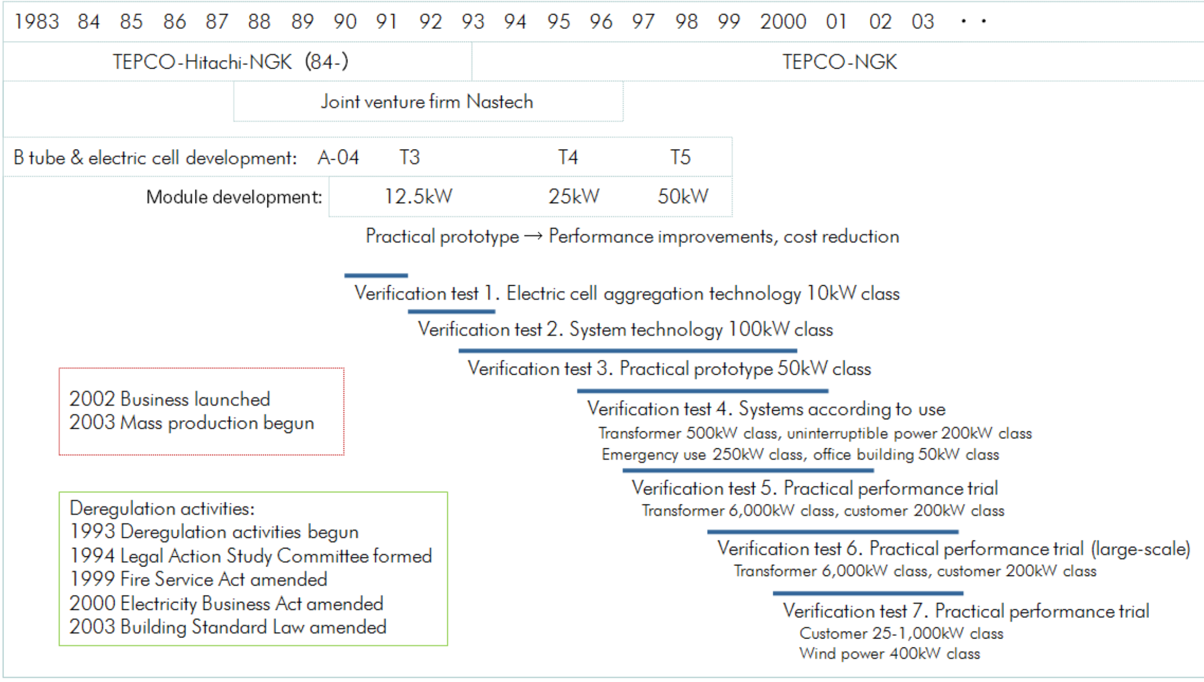
With the establishment of Nastech, NGK's NAS battery development activities moved into high gear. Nastech's head office was opened within NGK's headquarters[68] and a development group of about 40 individuals took up NAS battery development by being seconded to Nastech. Noboru Yamamoto, who as head of the laboratory at NGK served as the technology leader, assumed the position of Nastech's first president, and was succeeded by Kokuji Kito, who had served as Deputy General Manager of NGK's Electric Power Business unit, in 1991[69]. When development of the mass production technology was decided in the same year, the best engineers were gathered from among the top people throughout the entire company, and by the time Nastech was dissolved in 1997 the development team would grow to about 100 people. Nastech was in reality NGK's stronghold for NAS battery development[70]. On the other hand, TEPCO had also attracted engineers from ceramics manufacturers, and in 1989 changed the organizational position of the development team. NAS batteries had been merely one of the research themes of the Electric Energy Laboratory of the R&D Center, and three or four people had been responsible for this research. But in 1989, the group was set up as an independent "Electric Energy Storage Laboratory" as part of a reorganization of Technical Research Institute. Although the Electric Power Storage Laboratory was initially launched with four or five individuals, following development of the 50kW prototype machine the staff increased to about seven people.

The mission assigned to the NGK development team at Nastech was to apply the NAS battery technology BBC had developed for electric vehicles to electric-load leveling. As shown in Figure 5, electric cell development overlapped development of the β alumina tubes, and in the 1990s the production of modules based on aggregation of the electric cells and system verification tests were begun. Although the module systems were

65 Nihon Keizai Shimbun (December 23, 1991).
66 NGK Insulators (1997).
67 Takayama (2004).
68 Nihon Keizai Shimbun (January 12, 1988).
69 Nihon Keizai Shimbun (January 12, 1988) and Nikkei Sangyo Shimbun (July 2, 1991).
70 In conjunction with a reorganization of the Power Business Group in July 1990, the NAS Development Division was set up within this business unit, and Takashi Isozaki was appointed the NAS Development Division's first general manager (Nikkei Sangyo Shimbun, July 3, 1990). Nastech's NAS battery development team was also put under the Electric Power Group's NAS Development Division.

created initially using batteries based on the BBC design (but manufactured by NGK), capacity enlargement and optimization of the design for load leveling proceeded subsequently. This is because the specifications for batteries for electric load leveling differ from the specs for electric vehicles.

Figure 5. Main schedule of the TEPCO-NGK project



Source) Prepared by referring to TEPCO (2007), TEPCO-NGK (2006) and records of interviews at both companies.

First, a 10kW module battery using the BBC-designed “A-04 type” electric cell was built for trial purposes. From March 1990, a 10kW class system using the same module was evaluated at the electricity storage testing installation at TEPCO’s Kawasaki substation[71]. In competition with a system made by Hitachi, a 10kW system configured by NGK that used 1,320 electric cells was put through verification testing of the method for connecting electric cells. In the following year, a 100kW class system for trial purposes was fabricated by connecting twenty five 4kW modules that used the A-04 electric cells and the “B11 type” insulation container designed by BBC, and verification testing was begun from October 1991[72]. The purpose was to verify the control method when the modules were aggregated.

The “T3 type” NAS electric cell for electricity storage manufactured by NGK and a 12.5kW module produced by aggregating these cells were completed in 1991. In December of the same year a 50kW class system comprised of four 12.5kW modules was put through operational testing at NGK headquarters, and verification testing of the cells connected to the electric power system at a TEPCO substation was begun the following year from December 1992[73]. As the minimum NAS battery system unit to connect to the

71 Nikkei Sangyo Shimbun (July 30, 1991).
72 Nikkei Sangyo Shimbun (January 27, 1992).
73 Nihon Keizai Shimbun (23 December, 1991; December 22, 1992).

electric power system, the 50kW class system was considered optimal from the viewpoints of cost, ease of maintenance and transport efficiency by truck. Moreover, the development of β alumina tube processing technology was advancing at NGK, and NAS battery longevity was rapidly improved by introducing BBC's basic battery structure. As a result, the 50kW system, which had been moved to verification testing at the end of 1992, was positioned as the "practical prototype" in which the basic elemental technologies were established. In the subsequent development process, priority was placed on system enlargement and overcoming incidental technical issues. Akiyasu Okuno, who was involved consistently in NAS battery development at TEPCO since 1988 and who now in 2007 is manager of the electricity storage research group, described the activities as follows.

> I'd say that by 1991, the technologies, the elemental technologies had been established. Then in 1992, we conducted the first real field tests, by connecting to the grid in the actual field at our substation and running the initial inter-connected testing. That was just the 50 kilowatt practical prototype, though. Everything until then, I think, was pretty much at the basic elemental technologies development stage[74].

Furthermore, Tachibana made comment on the progress of development following the technology introduction from BBC and the transition of the development phase.

> The number of continuous charge-and-discharge cycles without failure improved immediately after the technology from ABB was introduced. When you see a historical chart of the NAS battery's technical development, you would notice that at first the batteries failed after 100 cycles or less, and then at a certain point they just suddenly improved. That sharp jump occurred when NGK introduced ABB's technology. The battery's structure was totally different from Hitachi's. It was different from Yuasa's structure either. It's ABB's proprietary structure. I cannot emphasize more the significance of the unique structure of ABB's. What I mean is that if it weren't for this structure, the NAS battery technology would never have been commercialized in the world. . . . I only understood later, after having observed how Hitachi and Yuasa struggled, that NGK had bought time. The ABB's basic structure was as such overwhelmingly excellent. On the other hand, ABB recognized its limitations on the ceramics technology, including, perhaps, thermal compression bonding technology as well. This is the technology for joining metal and ceramics. . . . Thus, ABB decided to work together with NGK at that time through such a give-and-take relationship for its development of NAS battery for EV. NGK, on the other hand, decided to develop a large battery for electricity storage based

[74] Quoted from the interview record (February 9, 2007). In 1993 Okuno was Senior Researcher at the R&D Center's Electric Energy Storage Laboratory; as of 2007 he works as manager of electric power storage solutions at the Research & Development Center group of TEPCO's Engineering Research & Development Division.

on ABB's basic structure. Since then, our major battle field of the development has been ensuring reliability and performance whilst enlarging the size of a cell[75].

On the other hand, Hitachi, which had a competitive relationship with NGK for the supply of batteries during the joint development project, began electrical charge and discharge testing of a 10kW module comprising 200 electric cells in March 1992[76]. Hitachi and TEPCO terminated their joint development arrangement in the following year, however, and Hitachi decided to pursue independent research thereafter. An engineering center to expand the electric power system business within the Power Systems Division was established at Hitachi in 1997, and a program to develop a one million kW class system by putting the center in charge of NAS battery development and channeling investment through the center was announced[77]. Hitachi's plan was to develop a power supply system combining 12.5kW of NAS batteries with wind power and solar generation capacity and begin verification testing at its Electric Power and Electric Equipment Development Group in Hitachi City in March 1998.

3-4. Progress of joint development and declining cost of pumped-storage

TEPCO's role as the customer that would actually operate the NAS batteries increased once the project entered the verification test phase. Through various exchanges that accompanied the verification tests, the NGK and TEPCO development teams bounced their know-how on electric power equipment quality control and quality improvement off each other and boosted the NAS battery performance. On the other hand, the cost to introduce pumped-storage power generation declined significantly during this period in anticipation of future electricity deregulation. It threatened the continuation of the NAS battery project that had sought to replace such systems. Yet the project had the support of both companies' management, and the investment in NAS batteries was maintained even under TEPCO's policy of curtailing its R&D budget. The project focused on lowering the cost by developing technology to enlarge electric cell capacity that would lead to reducing the number of components. Because the verification tests were conducted assuming NAS battery commercialization, efforts to seek easing of regulations that might restrict NAS battery installations were also pursued in cooperation with other companies. Furthermore, it was decided to carry out verification testing of the system installed in customers' properties, in addition to the system for substations, which until that time were considered to be the main site for NAS battery installation. This decision proved to be an important gambit when NAS battery commercialization was begun later on.

Following completion of the 50kW prototype, enlargement of electric cell capacity and module improvements were achieved by NGK and TEPCO from around 1993. Conducting verification tests of a system connected with the electric power grid, the project aimed for enlargement of the system. Although the basic elemental technologies for the 50kW

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[75] Quoted from interview record (February 9, 2007).

[76] Nikkei Sangyo Shimbun (March 23, 1992). According to this article, battery life at the time in 1992 was about two years and the system construction cost was about 100 times that of pumped-storage power generation.

[77] Nikkei Sangyo Shimbun (August 22, 1997) and Nihon Keizai Shimbun (December 25, 1997).

prototype device were established at that time, it took 11 more years until mass production was begun in 2003. During this 11-year period, the joint development organization comprised of the manufacturer (NGK) and customer (TEPCO) can be said to have had a major influence on the progress of the development activity.

Electricity storage using NAS batteries is accomplished by joining electric cells into modules, then combining these modules to make a system to connect with the electric power grid. In the development process, various problems occurred during testing at the module phase and at the system verification test phase, although the NAS batteries operated normally as electric cells. During each phase, it was necessary to analyze the problems and plan countermeasures. Material leaks and β alumina tube damage occurred as the result of factors not predicted at the design and fabrication stages, partly because NAS batteries operate at high temperatures. The development teams at TEPCO and NGK made it a practice to meet not only when trouble occurred, holding a "reporting session" once a month. At these reporting sessions, troubles were confirmed and problems were analyzed getting back to fundamental principles of quality control. To solve problems, issues to be addressed, such as tests and inspections, were discussed and decided for the next.

TEPCO and NGK's know-how concerning electric power equipment quality control and quality improvement was combined through the process of addressing these problems. It was one of the biggest factors that supported the progress of the development activity. One wellspring of knowledge and experience that TEPCO enjoys as a power utility is that it analyzes, pursues and adopts measures to address, together with manufacturers, the causes of accidents originating in electric power equipment. Since Japanese customers could demand stricter electric power quality than in other countries, it's said that, through their routine activities, engineers at power utilities are thoroughly trained in electric power equipment quality control, investigation into the causes of accident, and quality improvement. NGK, which has continuously supplied electric power insulators, similarly possessed know-how and a corporate culture that is meticulous regarding thorough quality. Based on its business relationships over long years, NGK was accustomed to the ideal approach to quality control at power companies. In this project, manufacturer and customer worked closely together to overcome and improve the problems arising from enlargement of the NAS battery system. This proved effective for ensuring the quality that had to be achieved eventually as a product.

To develop a system for practical use, they had to act on three major issues[78]. These were the cost to introduce the NAS battery, the government regulations, and the product's applications. In particular, the cost to launch the product was a significant issue for all entities developing battery-based system of storing electric power that sought to replace pumped-storage. The cost issue cast a shadow over the TEPCO and NGK project as well until after commercialization. The issue was one of the two major difficulties that threatened the project's continuation in the 1990s.

Development had been undertaken by envisaging the installation of NAS batteries at substations in urban neighborhoods, just like other battery-based electric power storage

[78] Based on Okuno (1993), Shito (1995) and Tachibana (1996).

systems, to replace pumped-storage power generation. This was the reason why one of key development goal was set as lowering the cost to introduce the system to less than the pumped-storage power generation cost of 300,000 yen per kW. Over the ten years from the project start, however, the "build and operate" cost of a pumped-storage power station continued to decline, falling to about 200,000 yen per kW in the latter half of the 1990s. The drop in the target cost, which was the project's "rival," made achievement of the goal difficult. Assuming the goal could not be reached, however, would call into doubt the necessity of the project itself.

Originally, the cost to introduce pumped-storage power generation was high and cost reduction was seen as the main issue. It was the reason development of a battery electric power storage system was planned. In addition, as the difference between domestic and foreign electricity rates gained growing attention in the 1990s, people began to discuss how Japan might proceed with reforms similar to the earlier deregulation of the electricity business in Europe and the U.S. In 1995, as the first step of the deregulation known as electricity liberalization, the Electricity Business Act was amended for the first time in 31 years. Owing to the amendment, IPP (Independent Power Producers) were permitted to enter the power generation business. Under Hiroshi Araki, who was company president from 1993 to 1999, TEPCO anticipated the progress of electricity liberalization and decided to implement a serious company-wide cost-cutting effort[79]. Based on its company-wide cost reduction policy, power plant construction and operating procedures were reviewed, and significant cost reductions were achieved by introducing a separate order system and expanding overseas procurement of materials[80]. As the result of introducing new works to shorten operations for steep gradient channel excavation and dam surface treatment, TEPCO was able to slash the construction cost by 15 billion yen, while further cost reductions were achieved in pumped-storage power station construction by introducing new night-time electric power conditioning technologies[81].

Spurred by the increasing difficulty of achieving the project goals in the wake of the declining cost of pumped-storage power generation and the prolonged development period, voices questioning allocation of the resources and personnel for the NAS battery project began to be heard within TEPCO around the year 1995. They complained, "How much are we going to have to throw at this project before we get a product?" or commented, "If we waste money and have nothing to show for it, we're just doing it for our complacency." Although a large fuel cell development project had been pursued at TEPCO since the 1980s in parallel with the NAS battery, it was unable to achieve targeted results, and was recognized as a case "that did not go well"[82]. The example of fuel cells generated distrust toward large projects like the NAS battery, and was brought up whenever resources for the NAS battery were mobilized.

To cope with the issue of reducing the NAS battery cost, it was decided to proceed

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[79] Nikkei Sangyo Shimbun (April 7, 1994; June 15, 1995; December 17, 1996).
[80] Nihon Keizai Shimbun (January 7, 1995; March 5, 1996).
[81] Nikkei Sangyo Shimbun (June30, 1994; January 17, 1994; February 7, 1995).
[82] Because they are less likely to cause air pollution problems and require limited installation space, and their waste heat can be used for heating, an effort was undertaken to develop fuel cells as a "distributed urban power plant" that can be installed in neighborhoods near the source of demand similar to the NAS battery. (Nikkei Sangyo Shimbun, March 17, 1983).

with development centered on enlarging the electric cell capacity. To apply the electric cell Nastech had developed for electric vehicles to electric-load leveling, the electric cell capacity had been enlarged. The 160Ah T3-type electric cell had been developed in 1991, followed by the 320Ah T4 in 1996[83]. The cost to introduce the NAS battery at this time, however, was about 3.0 million yen per kW. Because of the growing demand from the mid-1990s to lower the cost, the focus was set to achieving a further enlargement of the electric cell capacity from this time forward. The electric cells were the key component of the modules that would constitute the power storage system. Since enlarging the electric cell capacity would reduce the number of modules and system components, this was an efficient cost reduction measure. There was a trade-off, however, in that enlarging the electric cell capacity lowered the energy efficiency. Consequently, technical progress went back and forth between enlargement of electric cell capacity and enhancement of energy efficiency on the trade-offs.

TEPCO's Tachibana offered the following observation about the difficulties resulting from declining pumped-storage power generation cost and the prolonged development period, and the support of the top management.

> Pumped-storage had also become cheaper. This was one of the major impacts of the liberalization of electricity supply industry in Japan. The liberalization meant we could only win the competition by lowering our costs as quickly as possible. Reduction of all power plant costs became the primary issue of the management. We had assumed a pumped-storage power station cost of 300,000 yen per kilowatt, but now it is one hundred and several tens of thousands yen per kilowatt. Because civil engineering works are the heart of pumped-storage, the civil engineering division slashed cost by making a frantic effort. We had assumed the pumped-storage cost of 300,000 yen per kW as our target. We worked very hard to achieve that goal, assuming that the batteries would be commercially used once we could make them cheaper than that. But, the pumped-storage had become cheaper very quickly. . . . The only thing we could do against this was to enlarge the size of a cell. I think this was a big decision making for NGK as well, because enlarging the size of a cell meant shouldering that much development risk. The possible use of the batteries remained an open question. The target of cost fell very quickly. Things became really severe. As such, the period, when we couldn't see when at all we would be able to put the batteries to practical use, was pretty tough. I think the effort would have collapsed if the top management hadn't continually supported us during this hard time[84].

Under TEPCO's company-wide cost reduction policy, the R&D spending also peaked at 75 billion yen in fiscal 1993, and then continued to shrink until the first decade of the new

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[83] Ah shows the unit Ampere-hours, which indicates battery capacity. A 160Ah battery can supply 160 amperes for one hour or 1 ampere 160 hours. An ampere is a unit of electrical current. Electric power can be shown using watts (W) as a unit, electrical current using amperes (A) as a unit and electric potential using volts (V) as a unit.

[84] Quoted from the interview record (February 9, 2007).

century[85]. The reason R&D investment in the NAS battery was continued amidst the declining budget was that the battery was positioned as "one of the main themes for restraining investment in plant and equipment" at TEPCO. [86] It had been decided that restraint of R&D spending would take the form of focused investment in "technologies that would be effective in curbing plant and equipment investment."[87]

The second issue at this time was deregulation that would enable installation of the NAS battery. Since the sulfur and sodium used as raw materials in the NAS battery were treated as hazardous goods in the Fire Service Act, permits based on the Fire Service Act and the Building Standard Law would have to be obtained when installing the NAS batteries. It was believed the procedures based on laws and regulations that were expected to be necessary for installation might become a factor restricting NAS battery demand. Therefore, the central government was asked to ease its laws and regulations from 1993.

Invigorating the activity to deregulate installation were the collaborative research by the electric power industry, which continued until 1995 as the follow-up to NAS battery development under the Moon Light Project, and the existence of rival manufacturers such as Yuasa Battery and Hitachi. Deregulation based on a request submitted independently by a specific development entity contradicted government principles, and was expected to be difficult. Therefore, an "LL Procedure Response Study Committee" comprising nine Japanese power utilities led by TEPCO, NGK, Yuasa Battery and Hitachi as manufacturers and NTT as a customer was established in January 1994[88]. Highlighting the NAS battery's safety, the LL Procedure Response Study Committee sought deregulation at the Fire and Disaster Management Agency and Ministry of Land, Infrastructure, Transport and Tourism. As a result, a deregulation notification based on amendment of the Fire Service Act was issued in June 1999. Although the Fire Service Act set products' safety as the condition for deregulation, the NAS battery produced by NGK was certified as safe by the Hazardous Materials Safety Techniques Association in 2000. Furthermore, amendment of the Building Standard Law was approved in December 2003, greatly easing restrictions concerning implementation of open hearings, which had been obligatory for any installation of NAS batteries. Cooperation by not only TEPCO and NGK but by other power companies and battery manufacturers as well was vital for the realization of such deregulation.

To address the third issue of NAS battery uses, in 1994 the companies decided to develop and test units for customer installation in addition to the units for installation at substations, which had been the focus so far. Up to this point, NAS batteries had been assumed to be installed at electric power suppliers' substations. Now, in addition to this, the possibility that electricity customers have the means for electric power load leveling was examined and became a target of development. The individual who gave instructions to consider a system for installation at customers was Gaishi Hiraiwa, the president who had decided to begin the project and was chairman at that time. After completing the

[85] Nihon Keizai Shimbun (May 31, 2000).
[86] Nikkei Sangyo Shimbun (April 24, 1996).
[87] Nikkei Sangyo Shimbun (April 19, 1995).
[88] "LL" is an abbreviation for Load Leveling.

50kW prototype, the NAS battery development team wanted to start verification testing of an even larger substation installation system. Nevertheless, when the development team proposed a 1,000kW substation installation to TEPCO's management, Hiraiwa instructed the team to devote half of their effort to systems for installation at customers, noting that "the future of the business resides in distributed power system." In fact, development of distributed battery energy storage technology was underway in the government's New Sunshine Program and cogeneration equipment using city gas and oil as fuels was also expected to come into widespread use as a distributed power system with the push for electricity deregulation at that time[89].

The project received Hiraiwa's proposal and in 1995 began verification testing of a 500kW class substation system, a 250kW class system for customers that could serve as an emergency power supply, and a 50kW class system for office buildings, all using a 12.5kW module comprised of T3 electric cells[90]. The cost of these verification tests including the battery construction cost was about three billion yen[91]. In 1996, the following year, together with the completion of a 25kW module based on T4 electric cells, the project installed a 200kW class system for customers that could serve as an uninterruptible power supply, and began verification tests of a 50kW system delivered to NTT, the first customer that was not an electric power utility[92]. In 1998, verification testing of a 200kW class system for customer installation using the same 25kW modules was begun, and the actual load leveling effect and operating and maintenance performance were verified by modeling operating patterns of customers[93]. At this time, however, systems for substations were still regarded as the main application. Tests on the long-term reliability, construction methods, operation and maintenance of a 6,000kW class system, the practical size for substation installations, were performed in 1997.

As a result of having added systems for customer installation to systems for substation installation as a subject of the verification tests, the TEPCO development team, which was moved to the R&D Center in October 1994, increased its staff significantly. From a seven-member team when the 50kW power supply model was developed, staffing was boosted up to over 20 individuals as verification test locations multiplied and the team found itself short-handed. The organizational position of NGK's development team was also changed. The NAS Development Department to which the development team was assigned was renamed the NAS Development Division, and it became the NAS Business Promotion Division in 1995. In conjunction with the withdrawal of ABB (the successor to BBC) from NAS battery development in 1996, the NAS Business Promotion Division was elevated to the NAS Battery Division. The development team, which had grown to roughly 100 people, was reassigned to this division. Takashi Isozaki, who had led the development team since the start of the project, became the first NAS Battery Division general manager, and was succeeded in 1997 by Yoshihiko Kurashima. Kurashima, the

[89] In addition to the expected diffusion of cogeneration equipment, the Nikkei Sangyo Shimbun (May 5, 1994) cited another reason for this kind of examination. That is, systems for customers could be made ready even with the technology level at that time because they would need less than 10% of the electric power capacity of a system for substation installation.
[90] Nishimoto and Terasawa (1996).
[91] Nihon Keizai Shimbun (March 8, 1995).
[92] Nihon Keizai Shimbun (August 17, 1996) and Nikkei Sangyo Shimbun (November 18, 1996).
[93] Sato (1998).

former NAS Business Promotion Division general manager, led the team until 2001[94]. ABB's withdrawal from NAS batteries also eliminated the restriction preventing NGK from selling NAS batteries overseas beyond the Far East.

When NGK later turned to NAS battery commercialization phase, the 1994 decision and subsequent verification tests concerning the system for customer installation proved to be critical foundations.

3-5. A second round of difficulties and redefinition of uses

With the completion of the T5-type electric cell and 50kW module, the NAS battery reached its technical practical performance and the introduction cost was greatly reduced. Because pumped-storage power stations had excess capacity by the end of the 1990s, however, two new positions for NAS batteries were contemplated as alternatives to pumped-storage. One was a distributed power source for installation at customers that would bind customers to power utilities after deregulation, based on cheap electricity rates and stable electricity quality. NAS batteries were expected to supplement and protect the consistent electric power supply operations power utilities had traditionally managed. The second was a device to stabilize the intermittent output from clean energy power generation, which was increasingly demanding in this world. NGK decided to announce its NAS battery business plans, and promote these additional battery functions to its customers while putting more focus on the development of overseas markets.

The completion of the "T5" electric cell in 1998 provided an opening to solve the problem the project encountered in the mid-1990s, that is, the decline in the target introduction cost accompanied by a decrease in construction and operating cost of pumped-storage power generation. The T5 successfully boosted battery capacity to 632Ah, 2.5 times greater than earlier batteries, and the 50kW modules and systems produced by clustering these achieved a significant cost reduction. The cost to introduce the NAS battery system was lowered from three million yen per kW to 1.2 million yen[95]. Compared with the older T4, the T5 not only enlarged capacity but also improved energy density by 20% and reduced the space required for installation to three-quarters the space previously needed. Reduction of electric cells necessary for the system was made possible because repeated development efforts solved the problem of trade off between capacity enlargement of cells and energy efficiency up to certain level.

In 1999, a 6,000kW system for substation installation and a 200kW system for installation at customers were fabricated using 50kW modules consisting of T5 cells and supplied for verification testing. These were verification tests for the "practical application phase" of systems for installation at substations and customer locations. The project continued efforts to cut the cost by establishing the mass production technology, rationalizing the design and finding alternative, inexpensive raw materials. At this point, however, the project was thought to have reached the "region of technically practical

[94] Nikkei Sangyo Shimbun (July 2, 1996; June 30, 1997; March 26, 2001). Takao Totoki, who was general manager of the NAS Battery Division Manufacturing Department, served as the division manager from 2001, and was followed by Taku Oshima, who was the division's technology general manager, from 2004 (Nikkei Sangyo Shimbun, March 26, 2001, March 24, 2004).

[95] "Prospects for Large-scale Practical NAS Battery Application", *Koken*, Vol. 36 No. 6, June 1998.

application" and the basic technology completed[96].

However, as the 1990s drew to a close, the project faced with the second major difficulty. Because pumped-storage power stations were holding excess capacity at this time, doubts about the need for alternative devices began to be expressed. The possibility that strong demand could no longer be anticipated for an alternative to pumped-storage power generation, the main application considered at the start of the project, had to be contemplated. From the 1970s through the 1990s, power utilities had proceeded with pumped-storage power station construction owing to the growth in power demand. Because pumped-storage power station construction and survey techniques had progressed during these 20 years, site restrictions had been eased, and construction costs had declined as well. Moreover, the rate of growth in maximum power demand has slackened. As a result, after bottoming out in 1994, the electric power annual load factor had followed a rising trend, as shown in Figure 2[97]. Consequently, with regard to the maximum demand for electric power, people began wondering, "Won't we be unable to respond sufficiently by the current pumped-storage facilities?"

Overcoming this crisis and commercializing the NAS battery therefore required the development of new uses to take the place of pumped-storage. At the instruction of senior management, TEPCO created an "Advisory Committee on Measures for Practical Application of NAS Batteries" and encouraged a company-wide push to develop uses. Eventually, the distributed power source installed at customers was set to one of main applications of the NAS battery.

As deregulation of electric power moved forward, amendment of the Electricity Business Act authorized new entrants into power generation business in 1995, and electricity retailing in 1999 subsequently, selling to large-scale electric power customers such as large-scale plants and supermarkets. It became possible for customers who had been buying electricity from power utilities before this time to purchase electric power from other sources, and to cover demand using private power generation. Customers wanted less expensive electricity rates, and were expected to halt purchases from power utilities. At TEPCO, this deregulation created a serious need to establish a plan to counter the supply of electric power by other companies or by customers themselves.

By installing NAS batteries, customers themselves could perform electric power load leveling and use inexpensive night-time power effectively. Moreover, since NAS batteries can serve as an electric power backup system which has multiple functions of an emergency power supply, uninterruptible power supply or power supply in the event of a momentary voltage drop, users can obtain stable electricity quality. The NAS battery was positioned as a "device to provide customers with lower electricity rates and stable electricity quality, while maintaining the unified supply business encompassing power generation, power transmission and electric power supply managed until now by power utilities."

This pivot, from pumped-storage replacement based on installation at power utility substations to maintaining customers under electricity deregulation, was made possible

[96] Nikkei Sangyo Shimbun (May 27, 1998).
[97] The annual load factor has been declining again since 2001. When the annual load factor until 2005 is examined, however, it appears to be on a long-term improvement trend.

by the verification testing decision taken in the mid-1990s. Because verification testing of systems installed at customers had been undertaken since five years earlier, the project was able to proceed smoothly to shift the market target when it became necessary.

Besides, growing demand from the 1990s for reducing carbon dioxide (CO_2) gas through clean energy use thought to have spurred the spread of NAS batteries. Since the output from clean energy sources such as solar and wind power generation varies greatly depending upon the weather, their instability as a power supply was regarded as a serious problem. If these sources could be coupled with NAS batteries, it would be possible to stabilize power supply through electricity storage at low loads. Hence, NAS batteries were also positioned as a "supplementation device to stabilize clean energy power generation output" for which demand would increase.

At NGK as well, which had established the NAS Battery Division in 1996, continuing the project by focusing mainly on installation at customer sites such as factories was affirmed from the standpoint of keeping the battery technology in-house, and by TEPCO's indication of its intention to carry on. Although the need to install NAS batteries at power utility substations had been lessened by the construction of pumped-storage power stations, demand for inexpensive, stable electric power at electricity customers was expected to grow[98].

In its "EXCEL-01" Five-Year Medium-Term Management Plan in 1997, NGK announced it would begin operations at its NAS battery mass production plant in fiscal 1999 and seek to expand the business to 30 billion yen in five years[99]. The plan was revised in subsequent years, and NGK announced it would begin mass production of NAS batteries in 2002 as a "key next-generation product in the electric power sector" and seek to achieve annual net sales "to regular companies," i.e. customer firms other than electric utility, of 30 billion yen[100]. One factor behind the accelerated commercialization of NAS batteries might have been the drop in domestic sales of insulators, NGK's core product, as power utilities restrained capital investment because of electricity deregulation[101]. NGK's sales in its power-related business centered on insulators peaked at 99.5 billion yen in the fiscal year ended March 1993, then traced a downward trend, reaching 67.6 billion yen in the fiscal year ended March 2000[102].

As shown in Table 3, starting with Chubu Electric in October 1995, NGK delivered NAS batteries to power utilities other than TEPCO, including Tohoku Electric, Hokuriku Electric and Chugoku Electric, for the purpose of verification testing. Until about 1998, the main customers were power utilities in Japan[103]. However, once the basic technology for practical application was considered to have been achieved with completion of the T5 electric cell, NGK announced plans to sell to large-scale customers through the introduction and verification testing of a 500kW system, using itself as a customer[104].

98 Nakabayashi (2004a).
99 Nikkei Sangyo Shimbun (April 11, 1997).
100 Nikkei Sangyo Shimbun (July 15, 1998).
101 Nikkei Sangyo Shimbun (December 8, 2000).
102 Based on NGK's Annual *Securities Report*.
103 Nakabayashi (2001) and Nihon Keizai Shimbun (November 23, 1998).
104 Nikkei Sangyo Shimbun (July 15, 1998).

Table 3. Main verification tests of NAS batteries made by NGK

Year	Installed capacity (kW)	Entity	Installed location	Main use	Remarks
1990	10	Tokyo Electric Power	Kawasaki Power Storage Systems Test Site	Substation	A-04
1991	100	Tokyo Electric Power	Kawasaki Power Storage Systems Test Site	Substation	
1992	50	Tokyo Electric Power	Kawasaki Power Storage Systems Test Site	Substation	T3/12.5kW
1995	500	Tokyo Electric Power	Kawasaki Power Storage Systems Test Site	Substation	
	100	Chubu Electric Power	Technical Development Center	Substation	
	50	Tokyo Electric Power	TEPCO New Energy Park	Customer (office building)	
	250	Tokyo Electric Power	Kawasaki Power Storage Systems Test Site	Customer (emergency power supply)	
1996	200	Tokyo Electric Power	Kawasaki Power Storage Systems Test Site	Customer (uninterruptible power supply)	T4/25kW
	100	Tohoku Electric Power	Research and Development Center	Outdoor installation and cold region installation	
	50	NTT	Suzuka Training Center	Customer	First customer installation
1997	6,000	Tokyo Electric Power	Tsunashima substation	Substation	Establishment of standards and technology for substations
1998	200	Tokyo Electric Power	Kinugawa substation	Customer	Evaluation of high output operation for customers
	100	Hokuriku Electric Power	Local research laboratory	Substation/customer	
	25	Kandenko	Technical Research Institute	Customer	
	50	Chugoku Electric Power	Technical Research Center	Substation/customer	
	500	NGK	Head Office	Customer	T5/50kW
	210	Okinawa Electric Power	Miyakojima Solar Power Research Facility	Solar power supplementation	
1999	6,000	Tokyo Electric Power	Ohito substation	Customer	
	200	Tokyo Electric Power	Technology Development Center	Customer	
2000	1,000	Chubu Electric Power	Otaka substation	Substation	
	100	Hokuriku Electric Power	Yamada Village Ushidake Hot Springs Health Center	Customer	
2001	13	AEP(United States)	Dolan Technology Center	Substation	First overseas installation
	400	Tokyo Electric Power	Hachijo Shima Wind Power Station	Wind power supplementation	FY2002 commercialization target
	1,000	Asahi Breweries	Kanagawa plant	Customer	
	200	Tohoku Electric Power	Tsuden Electric Industries head office	Customer	Assumed commercialization at Tohoku Electric
2002	150	Fukuoka Prefecture	Fukuoka City Waterworks Bureau Otogana Water Purification Plant	Customer	Assumed commercialization at Kyushu Electric
	200	Tokyo Metro Government	Tokyo Metropolitan Tsubasa Sogo Senior High School	Customer	First residential area test
	100	AEP(United States)	Dolan Technology Center	Substation	Monitoring agreements with DOE, EPRI
2003	13	Tenaga Nasional Berhad(Malaysia)	TNB Research Sdn	Substation	Development in Asian countries
2007	500	Japan Wind Development	Miura Wind Park	Wind power supplementation	Preparation for Futamata Wind Power Station construction

Source) Prepared from secondary reference materials.

As NAS battery sales in 1999 were weak [105], domestic and overseas market development activities began earnestly in 2000[106]. First, although up until then customers had been solicited by NAS batteries' peak power control function, it was decided to highlight their additional functions, namely, emergency power supply and uninterruptible power supply functions. Second, NGK came to emphasize overseas market development. Due to ABB's withdrawal from NAS batteries, more aggressive overseas deployment was now possible because restrictions on sales were removed. Business development in the U.S. market began to be considered, following receipt in 2000 of an order for NAS

105 Nihon Keizai Shimbun (October 27, 1999).
106 Nihon Keizai Shimbun (December 7, 2000).

batteries for verification testing from American Electric Power (AEP), a large power company in the United States[107]. In the United States, unstable electricity quality due to excess rationalization following electricity liberalization was seen as a serious problem, as symbolized by the California electric power crisis, and demand for uninterruptible power source equipment had increased owing to the expanding use of computers. Moreover, the use of renewable energy had grown along with heightened environmental awareness in Europe and America. All of these circumstances were seen as creating business opportunities for NAS batteries.

With this redefinition of applications, final verification testing for customer installation and installation with wind power generators was begun around 2000, moving the project closer to commercialization. At TEPCO, internal R&D spending excluding personnel expenses was reduced by six billion yen down to 36 billion yen in fiscal 2001 because of a cutback in NAS battery verification test investment[108]. On the other hand, 5.2 billion yen was allocated for purposes such as “research to enhance NAS battery convenience as a service for customers.”

3-6. Technology development activities for reducing introduction cost

Following completion of the 50kW prototype in 1992, lowering the cost incurred to customers at introduction of the NAS battery continued to be a major issue for the project, along with ensuring durability and safety[109]. During NAS battery commercialization, the introduction cost was consistently a thorny problem for the project. While the spread of electricity liberalization provided the opportunity for NAS battery commercialization, it made the unit price level demanded by customers even more severe[110]. Just as a large reduction in the introduction cost was needed as an alternative to replace pumped-storage, a large reduction in the introduction cost was also necessary as a distributed power source installed at the customer. Although the initial cost was expected to fall as a result of mass production, various technical developments were carried out for commercialization additionally. Because enlargement of the electric cells for lowering the cost reduced energy efficiency, many efforts were put into increasing the energy efficiency.

As for the β alumina tubes, energy efficiency was improved by lowering the sodium ion conduction resistance. Moreover strength of the tube was also improved not to be damaged by the temperature rising and cooling process during operation of the enlarged batteries. For this purpose, technology to control the composition and crystalline structure of the raw materials, and inspection techniques to detect impurities and minute defects, were developed[111].

For the electric cells as well, greater energy efficiency was achieved by lowering the resistance of the cathode, which together with the β alumina tube accounts for 86% of the

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107 Takayama (2004).
108 Nikkei Sangyo Shimbun (April 20, 2001).
109 Ohara, who succeeded Takemi as NGK president in 1986, also spoke in an article in the Nihon Keizai Shimbun (December 8, 1991) about the difficulty of cutting the cost of installing NAS batteries, noting that “even if the cost drops in theory, cost reductions are difficult in reality.”
110 Based on the words by NGK president Atsune Matsushita in the Nihon Keizai Shimbun (January 13, 2005).
111 Isomura and Kajita (2004).

battery's resistance. In addition, anti-corrosion technology was developed to reduce the decline in battery capacity. Since the batteries could be damaged by the stress stemming from components' differed rates of thermal expansion and contraction during battery operation, a design to relieve the stress was adopted, and the strength of both the β alumina tube and the glass joint region was improved[112]. Furthermore, because the drop in the battery temperature activate the heater to maintain the operating temperature, thus, decrease energy efficiency of the module, radiation of heat from the insulating container was reduced by adopting a vacuum insulation design and an insulation mat.

To ensure safety, a "multiple protections" approach was adopted. The approach was to protect against damage to the electric cells, prevent active material from leaking if a cell is damaged, and finally prevent a cascade of failures if there is a leak by sealing the leak within the module. A safety tube to prevent active material from leaking was placed in the electric cells and a fuse to prevent excessive current was attached. The modules were designed to ease external stress from outside, and the spaces between the electric cells were filled with dry sand to limit the amount of oxygen and heat of reaction[113].

In addition to using inexpensive raw materials, and simplifying and standardizing parts, thorough efforts were made to shorten and automate mass production operations, because the batteries would be "fabricated from the most complex operations among any of the products handled by the company as a single product.[114]" For the β alumina tube manufacturing process, a direct synthesis method that greatly shortened powder processing from the 30 steps developed by Ford in 1977 to four processes, and a continuous synthesis furnace that shortened synthesis time by more than 85% were developed. For both the batteries and modules the manufacturing process was tweaked repeatedly, and an automated sodium filling machine, automated sulfur mold forming machine, and automated wire connecting machine were developed. The assembly and inspection processes were also automated by introducing robots.

For the system as a whole, development was undertaken to add an emergency power supply function, momentary voltage drop prevention function and an uninterruptible power supply function to NAS batteries. Besides, an easy-to-operate interface that would avoid most dangers for general customers was designed[115]. Finally, the equipment and installation construction costs were reduced by installing a battery control function to the battery packages to be delivered to general customers, and designing the packages with a prefab unit structure.

In addition to technological developments above, the ramp-up of production helped reduce the introduction cost. The opportunity to increase NAS battery production came with the start of TEPCO's activities to market the system to customers.

3-7. The final stage: start of sales activities and mass production

[112] Yoshida et al. (2004).
[113] NGK experienced a fire in a module battery during a voltage-resistance test at its NAS battery plant in Komaki City, Aichi Prefecture, on February 7, 2005 (NGK press release dated February 10, 2005). Because the safety measures based on the multiple protections concept had been adopted, however, the fire was not serious, and except for part of the inspection facility, operations were restarted in the following month (NGK press release dated March 24, 2005).
[114] Yokoi et al. (2004).
[115] Abe (2004).

NAS batteries were finally commercialized assuming two types of uses. First, customers are able to use them to lower electricity rates and stabilize electricity quality, while giving consideration to the environment. Second, customers are able to utilize the batteries to stabilize output from renewable energy power generation. Commercialization proceeded through the start of sales activities by TEPCO and the start of mass production by NGK. TEPCO strove to reduce customers' introduction cost by handling the NAS battery leasing, and contracted operation monitoring and maintenance services for the battery system. Other power utilities also began NAS battery sales activities in areas outside TEPCO's jurisdiction. As a result, NAS batteries began to be delivered to users such as sewerage treatment facilities, research institutions, factories, retail facilities and hospitals. Owing to the sales effort led by TEPCO and the start of mass production at NGK, NAS battery production rose and the introduction cost fell. Nonetheless, until 2005, as it was frequently pointed out that sizable initial cost prevented wide adoption of NAS batteries, further cost reduction efforts such as automation of manufacturing operations and standardization of parts were done. Signs of improvement in this situation were first evident in fiscal 2006.

The NAS battery project had moved to the commercialization phase through the reexamination of applications and target customers carried out around 2000. Sales of NAS batteries were encouraged by highlighting the following points. To begin, the benefits to electric power customers were divided roughly into three points. First, by installing NAS batteries, electric power customers would be able to achieve electricity cost savings without having to begin generating their own power or entering new transactions with electric power retailers other than power utilities. Second, while installation of NAS batteries required a considerable introduction cost, they eliminated the need for customers to separately prepare an emergency power supply function, momentary voltage drop prevention function and an uninterruptible power supply function, because the batteries provided these functions in addition to their basic load leveling function. Third, unlike other generating equipment, NAS batteries do not generate CO_2 or other gases and have a low environmental load because of their completely sealed structure. Accordingly, they can provide low electricity rates, and ensure high electricity quality, while addressing environmental problems. NAS batteries were seen as helping power utilities to maintain their unified electricity supply business using existing power lines and counter customer loss stemming from deregulation.

On the other hand, although the instability of output from renewable energy sources such as wind power had become a bottleneck hindering the diffusion of these alternative power sources, this could be overcome by installing NAS batteries in combination with such systems. Because countries were beginning to require power companies to use a certain percentage of renewable energy, it could be expected to produce a commensurate amount of demand for NAS batteries as devices to supplement these power sources.

Commercialization based on this clarification of users and selling points led to the start of development through two activities. These were the formation of sales and marketing team by TEPCO, and the construction and operation of a mass production plant by NGK. Around September 2001, TEPCO, decided to begin selling NAS batteries to its regular customers in 2002[116]. Because until that point the NAS battery project did not have any point of contact with the sales division, the sales division had initially doubts about the practicality of the batteries. Nevertheless, as the sales people recognized the product's merits, they turned to aggressive sales of the NAS battery to electric power customers. Satoshi Yabe, who served as the manager of the development planning group in the Development Planning Department at TEPCO's Engineering Research & Development Division, acted as the liaison between the project and the sales division. Since making the most use of developed technology in products or processes was recognized by the development planning group as one of its missions, successive managers of the group focused considerable effort on identifying NAS battery customers.

Spurred by aggressive encouragement from the Development Planning Department, a ten-member NAS battery sales team under manager Koji Tanaka was organized in October 2001 within TEPCO's Corporate Marketing & Sales Department. Five individuals, or half of the sales team, were transferees from the development group. The sales team would grow to about 25 people by 2007. TEPCO announced that it would begin selling NAS batteries in April 2002 for about 200,000 yen per kW to large-scale customers such as semiconductor fabrication facilities that use 500kW or more of electric power[117]. The initial cost to a customer to introduce 1,000kW of NAS batteries was about 200 million yen. The sales target for first year of business was sales of three billion yen based on orders for 15,000kW. TEPCO planned to not only sell NAS batteries but also provide after-sale battery operation monitoring and maintenance services.

Furthermore, three months before the start of sales in January 2002, the decision to begin an NAS battery leasing business was made[118]. This was a measure to prevent the sizable initial cost of the batteries from becoming an obstacle to their purchase. TEPCO would purchase NAS batteries from NGK, lease them to customers and provide battery operation monitoring and maintenance services. This was a mechanism to enable customers to use NAS batteries simply by paying the leasing fee each month, provided they signed a lease agreement with TEPCO for ten years. This leasing operation evolved into a business of batch leasing to customers' energy supply systems that minimized electricity rates by combining NAS batteries with equipment such as the "Eco-ice"[119] ice thermal storage air conditioning system[120]. TEPCO also worked to provide NAS batteries through the integrated energy supply business that TEPCO developed through a subsidiary in partnership with trading companies[121].

Following the establishment of the sales and marketing organization at TEPCO, TEPCO and NGK inked an agreement concerning sales, as they jointly had developed NAS battery and its business. The content of the agreement are as follows. First, TEPCO

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[116] Nihon Keizai Shimbun (September 2, 2001).
[117] Nihon Keizai Shimbun (October 20, 2001).
[118] Nikkei Sangyo Shimbun (January 18, 2002).
[119] "Eco-ice" is a thermal storage device developed by power utilities in Japan and companies such as Daikin Industries, Ltd., Hitachi, Ltd., Mitsubishi Electric Corporation and Toshiba Corporation. It uses inexpensive nighttime electricity to make ice that can then be used for daytime air-conditioning.
[120] Nihon Keizai Shimbun (December 5, 2002).
[121] Japan Facility Solutions, Inc., a company formed by TEPCO and Mitsubishi Corp., manages an energy conservation support business, and NAS batteries are incorporated into this business (Nikkei Sangyo Shimbun, May 7, 2003). The business provides integrated systems, as a project entity at each customer, for handling activities from receipt of electricity to maintenance checks.

would act as a window to sell the NAS batteries manufactured by NGK, and supply them as a system combined with other electric power equipment, within TEPCO's power supply jurisdiction. Second, TEPCO would provide services of monitoring operation and maintenance after NAS batteries were sold. In this case, NGK would earn the NAS battery sales revenue, while TEPCO would obtain the system sales revenue and income from the monitoring and maintenance services and thus could expect the buyers to remain with it as electric power customers. On the other hand, NGK could engage in both NAS battery manufacturing and sales activities outside of TEPCO's jurisdiction. Because commercialization had been achieved through the joint development system, however, TEPCO would receive a set royalty fee on such NAS battery sales. In the jurisdictions of power utilities other than TEPCO, the batteries were provided by power companies as a customer service in most cases, because the NAS battery benefits were related to electric rates[122].

Although sales through TEPCO eventually accounted for the largest percentage of sales, power utilities other than TEPCO also began preparations to sell NAS batteries from about 2001. Tohoku Electric Power Co., Inc., for example, had pursued the distributed power supply business including cogeneration equipment in those days as well as other power utilities. As it was assumed to use NAS batteries in this business, Tohoku Electric Power began verification tests at group companies aimed at installing the batteries at customers[123]. Moreover, at the end of 2001, Kyushu Electric Power Co., Inc. announced it would sell NAS batteries manufactured by NGK to its large-scale customers[124]. This was a plan to "foster solution-oriented sales approach as core" to maintain large customers, as part of them had begun to terminate their dealing with the company taking the opportunity of deregulation. Kyushu Electric began the verification tests assuming their NAS battery business at the Fukuoka City Waterworks Bureau in 2002, then started an NAS battery leasing business in 2003, expecting annual orders of 4,000kW[125].

The start of sales operations centered on TEPCO would greatly expand NAS battery shipments. Although full-fledged sales operations began from fiscal 2002, some customer deliveries were made during fiscal 2001. A 1,000kW NAS battery was introduced experimentally at Asahi Breweries' Kanagawa Plant in July 2001, followed by a delivery as the first "completed product" to the Tokyo Kasai Water Recycling Center at the end of the year[126]. Although the central government bore half of the introduction cost of 400 million yen, this transaction was not a verification test but a sale for which actual operation as a product was warranted. The Tokyo Metropolitan Government prepared a plan to continually introduce NAS batteries at sewerage system-related facilities, making Tokyo one key customer for the project's NAS business. As shown in Table 4, from 2003 through 2007, deliveries were made continuously to Tokyo for installation at the Shinmachi Water Supply Station, Koto Water Supply Station, Morigasaki Water Reclamation Center, Sunamachi Water Reclamation Center, Miyagi Water Reclamation

122 Nakabayashi (2004b).
123 Nihon Keizai Shimbun (February 14, 2001; November 2, 2001).
124 Nihon Keizai Shimbun (December 26, 2001: January 30, 2002).
125 Nihon Keizai Shimbun (February 7, 2003).
126 Nihon Keizai Shimbun (July 27, 2001).

Center and Kita-Tama Ichigo Water Reclamation Center. Especially large-capacity NAS battery complex totaling 8,000kW was delivered to the Morigasaki Water Reclamation Center. Urban sewerage-related facilities have a high electric-load leveling need because the quantity of electricity used varies intensely depending on rainfall, and water treatment for Tokyo's 23 wards alone consumes electricity corresponding to 1% of total electricity use in the Tokyo metropolitan area. Tokyo decided to continue introducing NAS batteries in order to save on its electric bill and reduce its CO_2 emissions volume[127]. From fiscal 2002 NAS batteries continued to be sold to research facilities, factories, retail facilities, universities, hospitals and other institutions, primarily within TEPCO's marketing territory.

[127] Nihon Keizai Shimbun (December 8, 2001; April 8, 2002).

Table 4. Examples of deliveries of NAS batteries manufactured by NGK

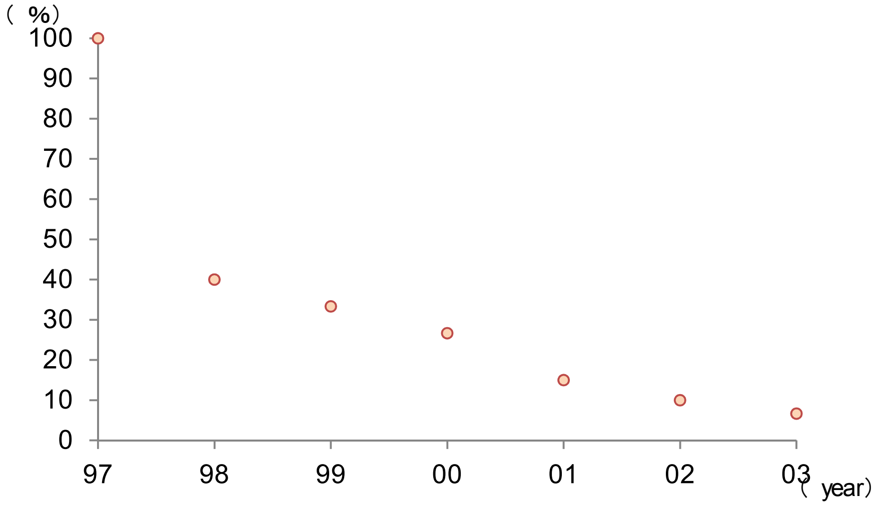
Year	Installed capacity (kW)	Entity	Installed location	Application	Reference
2001	1,000	Tokyo Metropolitan Government	Kasai Water Recycling Center	Customer	Nihon Keizai Shimbun (July 27, 2001; December 8, 2001; April 8, 2002; May 15, 2002)
2002	1,000	Fujitsu Limited	Akiruno Technology Center	Customer	Nihon Keizai Shimbun (June 12, 2002; July 17, 2002)
	1,000	Ito-Yokado Co., Ltd.	Two large Kansai Region stores	Customer	Nikkei MJ (February 5, 2002)
	1,000	Fuji Xerox Co., Ltd.	Ebina Office	Customer	NGK press release (December 16, 2002)
	800	Takaoka Electric Mfg. Co., Ltd.	Koyama office	Customer	NGK press release (December 16, 2002)
	2,000	Pacifico Yokohama	International Broadcast Center	Customer	NGK press release (December 16, 2002)
	400	City of Yokohama, Kanagawa Prefecture	Imai drainage basin	Customer	Nihon Keizai Shimbun (June 28, 2002); Yokohama website: "Environmental Preservation Efforts" (http://www.city.yokohama.jp/me/suidou/kyoku/torikumi/kankyo-hozen/nas.html)
	1,000	Meisei University	Hino campus	Customer	Meisei University (2007)
	1,000	TEPCO	Chichibu substation	Substation	NGK press release (July 21, 2006)
2003	200	Tokyo Metropolitan Government	Shinmachi Water Supply Station	Customer	Nihon Keizai Shimbun (March 6, 2003)
	300	Tokyo Metropolitan Government	Koto Water Supply Station	Customer	Nihon Keizai Shimbun (March 6, 2003)
	1,000	Tokyo Dome Corporation	LaQua	Customer	Nihon Keizai Shimbun (May 17, 2003)
2004	1,000	TEPCO	Kamiyama substation	Substation	Nikkei Sangyo Shimbun (August 15, 2003)
	1,000	TEPCO	Matsuo substation	Substation	Nikkei Sangyo Shimbun (August 15, 2003)
	8,000	Tokyo Metropolitan Government	Morigasaki Water Reclamation Center	Biomass power station support	Nikkei Sangyo Shimbun (March 27, 2003)
	500	Saga City	City Hall office building	Customer	Nihon Keizai Shimbun (June 11, 2003)
	na	City of Yokohama, Kanagawa Prefecture	Kaminagaya water supply pond	Customer	City of Yokohama press release (April 12, 2004)
	500	Taiyo Pharmaceutical Co., Ltd.	Takayama Plant	Customer	Nikkei Sangyo Shimbun (May 10, 2004)
	4,000	Japan Tobacco, Inc.	Kita-Kanto Factory	Customer	Nikkei Sangyo Shimbun (August 3, 2004); Energy Conservation Center, Japan website (http://www.eccj.or.jp/succase/07/G/kan07.html>
	8,000	Hitachi, Ltd.	Automotive System Group	Customer	NGK Fiscal 2004 Business Report (June 2005)
	1,400	Tokyo Metropolitan Government	Kasai Water Recycling Center	Customer	Tokyo Metropolitan Government, "Status Report on the Progress of Key Projects" (FY2004 interim report)" (October 29, 2004)
	250	Mochida Pharmaceutical Co., Ltd.	Otawara Plant	Customer	Nikkei Sangyo Shimbun (May 28, 2004)
	2,000	Tokai University	Tokai University Hospital	Customer	Nikkei Sangyo Shimbun (May 7, 2003)
	1,000	Canon Inc.	Hiratsuka Plant	Customer	Heat Pump and Thermal Storage Technology Center of Japan (2005), "COOL & HOT", no. 23
	2,000	Canon Inc.	Yako Office	Customer	Same as above
	na	Fujitsu Limited	Aizu Wakamatsu Plant	Customer	Nikkei Sangyo Shimbun (August 25, 2006); Fujitsu Limited "Plant Environmental Management Report Fiscal 2005" (http://jp.fujitsu.com/microelectronics/environment/factory/2005/index-p2.html)
2005	na	Mitsubishi Chemical Corporation	Tsukuba Plant	Customer	Nikkei Sangyo Shimbun (January 13, 2005)
	500	TOTO	Oita Plant	Customer	Nikkei Sangyo Shimbun (February 21, 2005)
	2,000	Tokyo Metropolitan Government	Sunamachi Water Reclamation Center	Customer	The outer area of Tokyo waterworks bureau'Environmental guide in drainage' (http://www.gesui.metro.tokyo.jp/kanko/kankou/kankyou/guide03.htm)
	2,000	Fujitsu Limited	Mie Plant	Customer	Chubu Electric Power Co., Inc. press release (April 27, 2005)
	na	Tamagawa Academy	Tamagawa University campus	Customer	Tamagawa Academy, "2005 Self-Review and Evaluation Report" (March 2006)
	500	City of Yokohama, Kanagawa Prefecture	Chubu Water Reclamation Center	Customer	City of Yokohama website, "ISO Pilot Project (Excellent Examples) Report" (http://www.city.yokohama.jp/me/kankyou/mamoru/iso/pilot/1708.html)

	2,000	Ito-Yokado Co., Ltd.	Ario Kawaguchi	Customer	Heat Pump and Thermal Storage Technology Center of Japan (2006),"COOL & HOT", no. 26
	2,000	Sankyo Co., Ltd.	Research & Development Center	Customer	Heat Pump and Thermal Storage Technology Center of Japan (2005), "COOL & HOT", no. 23
2006	1,500	Kirin Brewery Co., Ltd.	Toride Plant	Customer	Nikkei Sangyo Shimbun (March 8, 2006)
	1,000	Tokushima Bunri University	Tokushima campus	Customer	Tokushima sentence reason university press release (June 14, 2006)
	750	ITOCHU Techno-Solutions Corporation	Data Center	Customer	CTG Data Center website, "Advanced Efforts for the Environment" (http://www.crc.ad.jp/datacenter/nas.html)
	1,000	AEP	West Virginia	Substation	TEPCO press release (July 21, 2006); Nikkei Sangyo Shimbun (July 24, 2006)
	1,000	Fujitsu Limited	Mie Plant	Customer	Nikkei Sangyo Shimbun (August 25, 2006)
	2,000	Ito-Yokado Co., Ltd.	Ario Kameari	Customer	Heat Pump and Thermal Storage Technology Center of Japan (2006),"COOL & HOT", no. 26
	2,000	Fujifilm Corporation	Advanced Research Laboratories	Power supply and emergency power supply	Heat Pump and Thermal Storage Technology Center of Japan (2006),"COOL & HOT", no. 26
	2,000	Tokyo Metropolitan Government	Miyagi Water Reclamation Center	Customer	Tokyo Metropolitan Government Bureau of Sewerage, "Sewerage Environmental Guide" (http://www.gesui.metro.tokyo.jp/kanko/kankou/kankyou/guide03.htm)
2007 or later	na	Tokyo Metropolitan Government	Kita-Tama Ichigo Water Reclamation Center	Customer	Tokyo Metropolitan Government, "Status Report on the Progress of Key Projects" (FY2004 interim report)" (October 29, 2004)
	12,000	Honda Motor Co., Ltd.	Automobile R&D Center Tochigi	Customer	Honda Motor Co., Ltd., "HONDA Environmental Annual Report 2007" (June 26, 2007)
	34,000	Japan Wind Development Co., Ltd.	Futamata Wind Power Station	Wind power supplementation	Nihon Keizai Shimbun (January 30, 2007; April 20, 2007); Distributed Power Generation News (April 4, 2007)
	6,000	AEP	West Virginia, Ohio	Substation and wind power supplementation	Nihon Keizai Shimbun (October 4, 2007)

Source) Prepared by the author based on references shown in the table.

Together with the establishment of a sales and marketing organization by TEPCO, NAS battery commercialization was aided by the creation of a mass production system by NGK. NGK invested five billion yen to construct an NAS battery plant with annual production capacity of 65,000kW in Komaki City in Aichi Prefecture, which it began operation in fiscal 2003. A goal of increasing annual sales to about nine billion yen was set, with plans to expand annual production capacity up to 200,000kW within several years[128]. The increase of production volume with the start of mass production was expected to help lower the introduction cost of NAS battery as shown in Figure 6[129].

Figure 6. Change in estimated introduction cost per kW of NAS battery assemblies (1,000kW)



Note) The value for each year are indicated as a percentage with the value in 1997 as 100. Values are for the battery units only; the cost of converters that are combined with the batteries and construction costs are not included.

Source) Prepared with reference to Nakabayashi (2004b) and Nikkei Sangyo Shimbun (May 27 1998; February 9, 1999; December 38, 2001; January 18, 2002).

However, as lowering the introduction cost to the level customers demanded in the midst of electricity liberalization was no easy task, efforts including further automation of the production processes and standardization of components were made repeatedly even after commercialization [130]. The target value for the introduction cost of the battery alone was 150,000 yen per kW, even lower than the amount aimed at pumped-storage replacement. Until about 2005, slow diffusion of NAS batteries caused by the high introduction cost had been noted frequently[131]. The full-scale introduction at the company's substations announced by TEPCO in August 2003 was said to have had the

128 Nihon Keizai Shimbun (December 8, 2001; May 17, 2003).
129 Nakabayashi (2004b).
130 Based on words by NGK President Atsune Matsushita in the Nihon Keizai Shimbun (January 13, 2005).
131 See, for example, Nihon Keizai Shimbun (February 7, 2003; December 16, 2004; January 13, 2005).

partial aim of reducing the NAS battery price through TEPCO's own use[132]. Owing to the two companies' cost reduction push and sales efforts, growth in demand could be projected around fiscal 2006.

3-8. Outcome of the NAS battery project to-date

Let us look at business outcome of the NAS battery, TEPCO and NGK struggled over 20 years to commercialize. As of September 2006, about 80% of the two companies' NAS batteries have been installed mainly at electric power customers in TEPCO's jurisdiction; half are used for storage while concurrently serving added functions such as emergency power supply. At NGK, since their electric power-related business, in which the project was placed, had been strong in the market and some other diversified businesses had been growing gradually, prolonged NAS battery development had been supported financially. The company's NAS business, though sluggish earlier, improved earnings from fiscal 2006 and accounted for about 14% of all electric power-related business revenues in the same year. This was because overseas power utilities were beginning to think cutting capital investment using NAS batteries, and domestic demand for wind power generation was growing. TEPCO, on the other hand, has seen new market entrants grab more than 4% of the market in its jurisdiction in recent years, despite its efforts to maintain customers through price reductions based on investment controls. The impact of the NAS battery business on TEPCO's operating results is not affirmative. Still, if we simplify the matter, it possibly kept 5% of the TEPCO customers who might have switched to new players in the business, besides earning from NAS business alone. Despite the possible competition with various product technologies in the long run, as the first battery for electricity storage to be commercialized on a mass production scale, growth is expected for their NAS battery business.

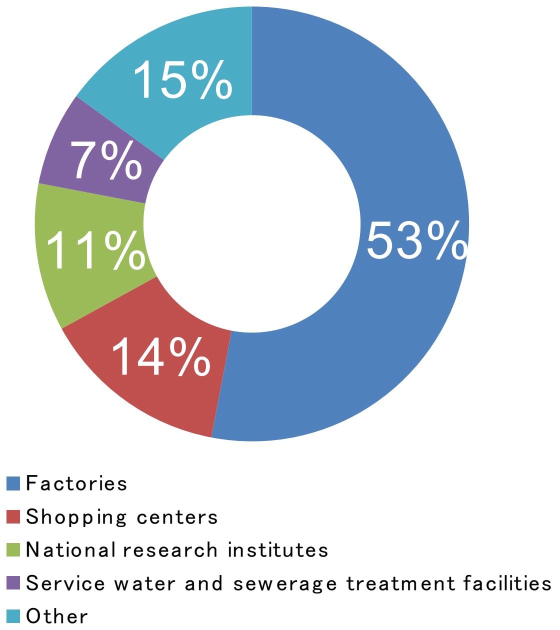
We look first at the types of the customers and their uses of the NAS battery. By September 2006, NAS batteries with capacity of 132,000kW had been delivered to 92 domestic locations for the customers shown in Table 4[133]. Of these, deliveries within TEPCO's jurisdiction were made to 71 locations for a total of 115,000kW, representing 77% of all delivery locations and 87% of total delivered capacity. In addition, 80% of revenues were from the use of leases, rather than from purchases. It appears that customers introduce the NAS batteries with lowered initial cost using leases and the system of central government grants[134]. As so many customers are in the Kanto area, the sales by TEPCO adopting the leasing system is thought to have contributed to the growth in NAS battery sales.

[132] Nikkei Sangyo Shimbun (August 15, 2003).

[133] The NAS battery delivery record shown here is based on TEPCO-NGK (2006).

[134] The government has implemented various support ptograms for projects that use energy resources effectively; one program that made the NAS battery introduction project eligible for assistance, for example, was the Advanced Load Leveling Equipment Introduction and Diffusion Model Project implemented by the Ministry of Economy, Trade and Industry.

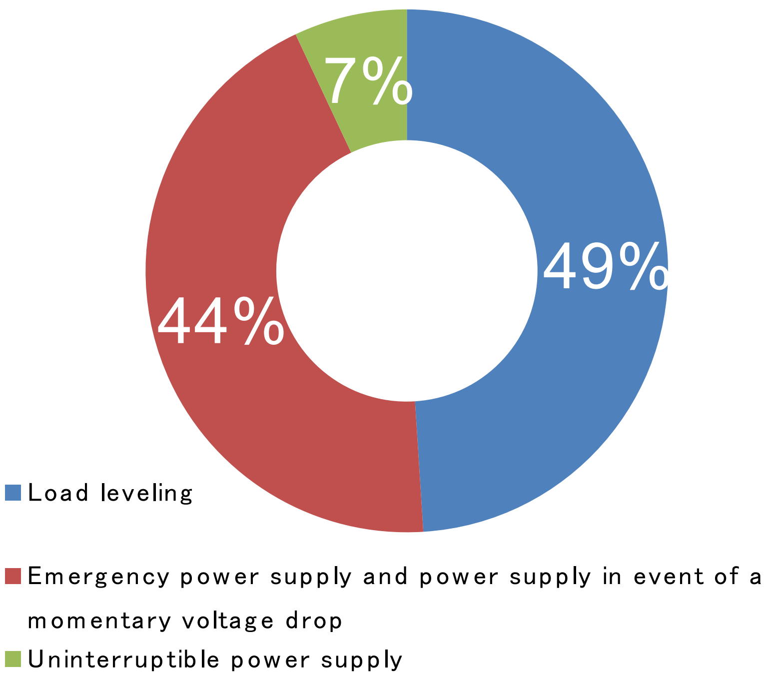
Figure 7. Percentage of NAS battery sales by customer category



Note) Cumulative through September 2006. Delivered capacity basis.

Source) TEPCO-NGK (2006).

Figure 8. Percentage of NAS battery sales by installed function

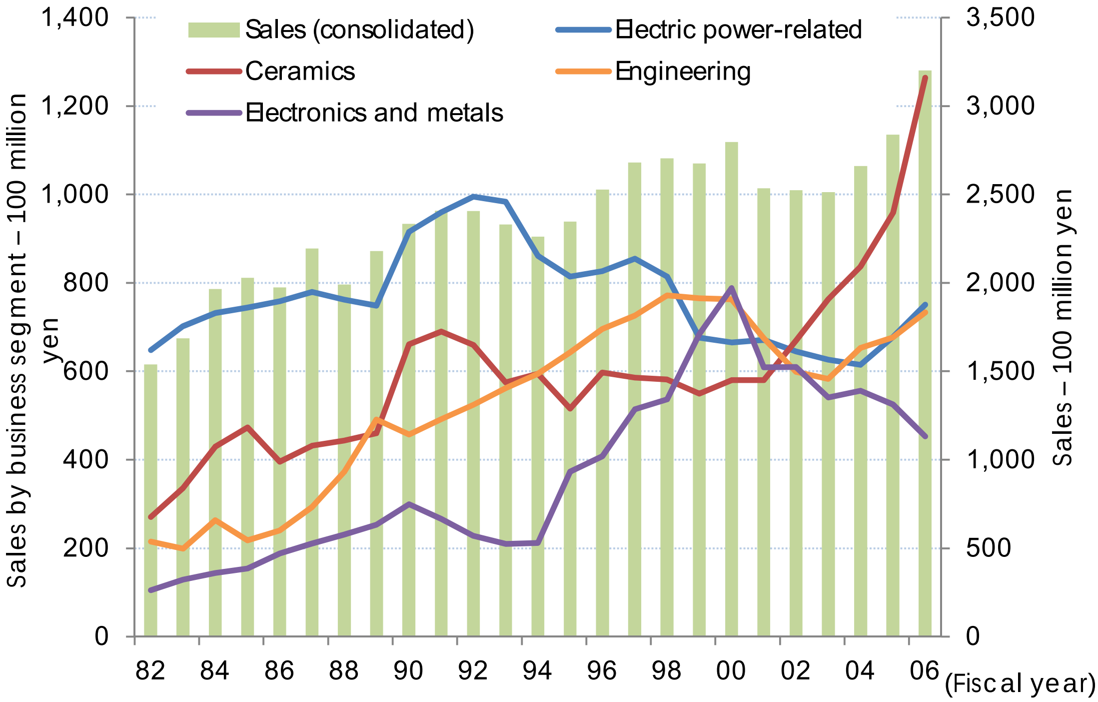


Note) Cumulative through September 2006. Delivered capacity basis.

Source) TEPCO-NGK (2006).

NAS battery installation locations are overwhelmingly at electric power customers rather than substations. When customers are looked at by business category, factories account for half of the locations on a delivered capacity basis as shown in Figure 7, followed by shopping centers, national research institutes and service water and sewerage-related facilities. According to surveys by TEPCO and NGK, the main reason for introducing NAS batteries differs depending on the customer. The major reason given by shopping centers such as supermarkets and department stores is "to reduce our electricity bill." In contrast, "to achieve a highly reliable power supply" and "ease of maintenance" to stably receive a high-quality power supply were given as the main reasons by service, water and sewerage treatment facilities, plants of semiconductor and precision parts manufacturers, and hospital facilities. At firms and schools with active environmental programs, "pollution-abatement measures are unnecessary" was cited as the main reason. Such differences in needs seem to have been reflected in the installed functions of the NAS batteries that were introduced. As shown in Figure 8, on a delivered capacity basis, 49% of NAS batteries delivered were for load leveling to help reduce customers' electric bills, and 51% had ancillary functions as emergency power supply, momentary voltage drop prevention, or uninterruptible power supply. This is attributed to the fact that achieving a highly reliable power supply is considered vitally important at factories, which account for half of customers on a delivered capacity basis.

Figure 9. Change in NGK's sales (consolidated) and sales by business segment

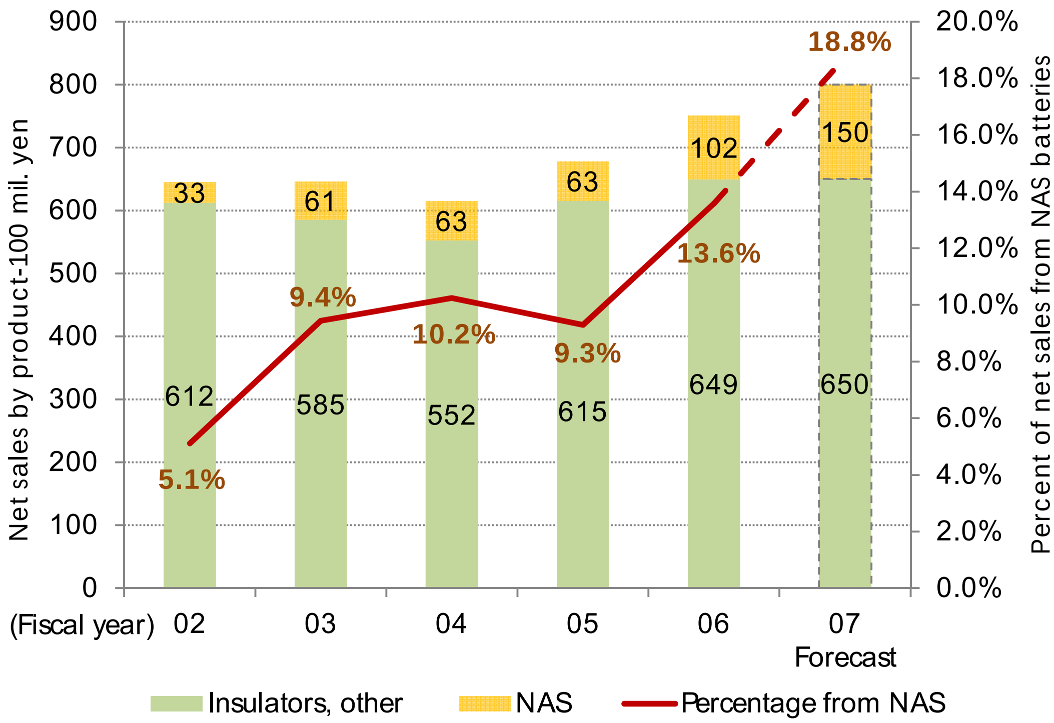


Note 1) To confirm the long-term trend in the change in sales, sales from fiscal 1999 through fiscal 2002 of Asahi Tec Corporation, which was temporarily subject to consolidation accounting during that period, have been excluded from "sales (consolidated)."

Note 2) "Sales by business segment" are based on non-consolidated data until fiscal 1989 and consolidated data after fiscal 1990, when NGK revised its presentation method. Moreover, the "electronics and metals" business is described in NGK's Annual Securities Report as the "Metals" business until fiscal 1995 and as the "Electronics" business from fiscal 1996. Ceramics components for printers are included in the "Ceramics" business until fiscal 1995 and reported in the "Electronics" business from fiscal 1996. There is a possibility reporting business sectors for products other than these were also changed during the calculation period.

Source) Prepared by referring to NGK's Annual *Securities Report*.

Figure 10. Change in net sales by product in NGK's electric power-related businesses



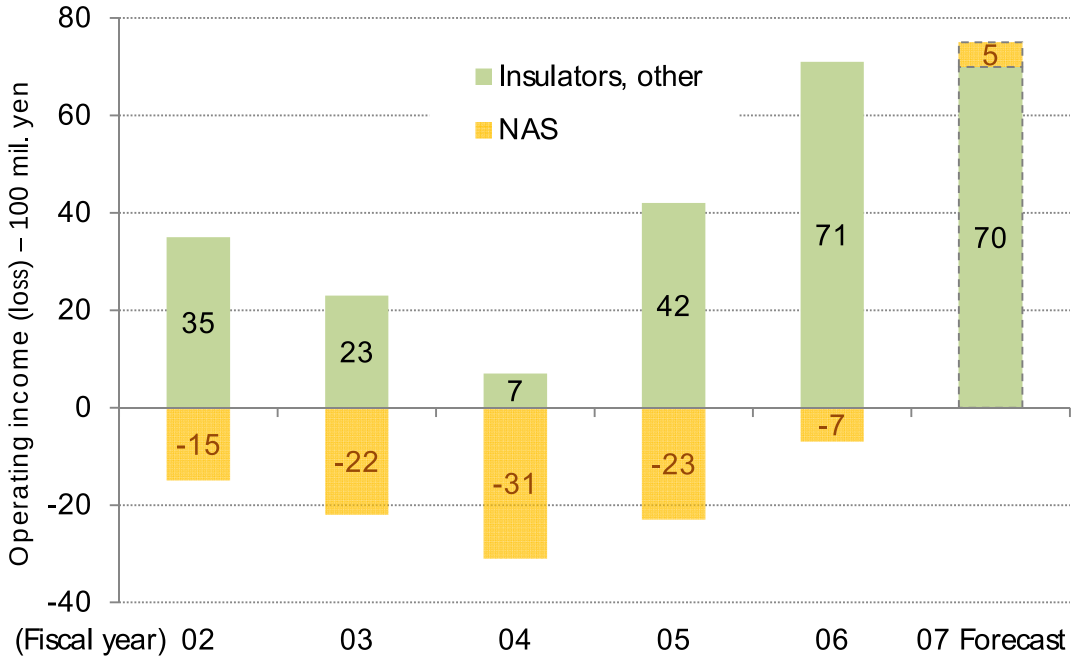
Note) Figures for fiscal 2007 are forecast values from NGK's interim reporting period (period ended September 2007).

Source) Prepared by referring to NGK's financial briefing presentation materials (May 12, 2006; October 30, 2007).

We next turn to examine the impact of the NAS battery business on the operating results at NGK. First, looking at the change in the company's sales, over the past 20 years total sales doubled to about 320 billion yen as shown in Figure 9. Looking into change in sales by business segment, however, the electric power-related business, including the insulator products indicated in the company's name, peaked in fiscal 1992 and, despite an upturn in recent years, appears to have settled into a long-term maturing trend. The ongoing restraints on plant and equipment investment at domestic power utilities are one cause of the decline in sales in this business.

The businesses that drove NGK's growth in place of the electric power-related business were the ceramics business, electronics business, and engineering business, all of which enjoyed rapid growth during this 20-year period. Despite a lull in growth during the 1990s, the ceramics business, which includes vehicle exhaust emissions filters for automobiles, achieved explosive growth in the 2000s, particularly with products for diesel-powered vehicles, as countries worldwide toughened exhaust emissions regulations. The metals business centered on beryllium copper products, which NGK had handled since the 1950s, was reorganized along with piezo-electric ceramics for printers and materials for mobile phones, which grew rapidly from the mid-1990s, into the electronics business. The business expanded at a fast clip until about 2000. The engineering business, established in the 1970s to develop sewage treatment equipment and incineration plants, also continued to grow until the 2000s. Since these businesses entered overlapping periods of growth, they created the time and resources to take off the NAS business. Even the electric power-related business, which experienced a decreasing trend after 1992, maintained an operating profit margin of 11%-15% until 1998[135] and can be said to have supported NAS battery development located within this business.

Figure 11. Change in operating income (loss) by product in NGK's electric power-related businesses



Note) Figures for fiscal 2007 are forecast values from NGK's interim reporting period (period ended September 2007).

Source) Prepared by referring to NGK's financial briefing presentation materials (May 12, 2006; October 30, 2007).

On the other hand, net sales for the NAS battery business per se showed an increasing trend recent year, as in Figure 10, When full-scale sales were begun following establishment of the sales and marketing organization in fiscal 2002, net sales were 3.3

[135] Based on NGK's Annual Securities Report.

billion yen. Although this figure doubled to 6.1 billion yen in fiscal 2003 when mass production was started, net sales remained at this level through fiscal 2005. In fiscal 2006, however, NAS battery business net sales exceeded the 10 billion yen, level set as the initial commercialization objective, and are expected to reach 15 billion yen in fiscal 2007. The business's improving trends from fiscal 2006 encompass not only net sales but also operating earnings. As shown in Figure 11, after a peak of 3.1 billion yen in 2004, operating losses began to shrink and the business is expected to turn a profit in fiscal 2007. This turnaround in the NAS battery business was made possible due to production process rationalization, plus increases in overseas sales and demand for NAS batteries to combine with wind power generation[136].

NGK worked in cooperation with TEPCO to deliver a 12.5kW NAS battery system in 2000 and a 100kW system in 2002 to AEP, a power company in the United States, for verification testing, and signed contract with the U.S. Dept. of Energy to monitor the tests[137]. The delivery contract at this time became the foothold for NAS battery business development in the U.S. market. In 2006, a 1,000kW class NAS battery was installed at an AEP substation in West Virginia. The NAS battery delivery to AEP received DOE certification as a "model project for power storage," making it eligible for a grant[138]. This was the first sale to the overseas market. It was thought that tremendous amounts of capital will be required for spreading systems of power transmission and distribution over the vast country like United States, besides clearing regulations for visual landscape[139]. If overseas power utilities begin utilizing NAS batteries to control capital investment in power transmission and distribution system infrastructure, they could become a major NAS battery customer in overseas markets.

To capture such demand, NGK decided to develop sales activities in North America, Europe and Australia. In 2007 it received an inquiry for a 1,000kW system for an outer island in the French territory of Madagascar from Électricité de France (EDF), a major power utility in France. EDF desired to supplement a vulnerable power generating facility on the island with NAS batteries. In the same year, NGK received an additional order for 6,000kW worth approximately 1.5 billion yen from AEP. AEP placed the additional order because it judged the 1,000kW system delivered in 2006 to have had an "excellent electric power stabilization effect"[140]. AEP announced it would utilize 2,000kW of the 6,000kW for stabilization of output from wind power generation.

Demand for NAS batteries as a wind power generation supplementation device was also expected to grow both domestically and overseas. In recent years the introduction of renewable energy has been promoted as a policy in many countries, and in Japan as well. The Special Measures Law Concerning the Use of New Energy by Electric Utilities, also known as the RPS (Renewable Portfolio Standard) Law, has been enforced since 2003, obligating electric power suppliers to use a certain proportion of renewable energy. Because the output of renewable energy power generation including wind power varies

[136] NGK's fiscal 2006 Annual Securities Report, fiscal 2006 Report of Business Operations, fiscal 2007 interim report, settlement of accounts briefing presentation materials (May 8, 2007;October 30, 2007).
[137] Norris et al. (2007) and AEP press release (614/223-1903, September 23, 2002).
[138] TEPCO press release (July 21, 2006).
[139] Nikkei Sangyo Shimbun (July 24, 2006).
[140] Nihon Keizai Shimbun (October 4, 2007).

as a result of factors such as weather, however, stabilization of output is considered to be a major challenge for wide use of such sources. Accordingly, demand for NAS batteries from entities such as wind power generation companies is expected to increase[141]. NGK and TEPCO began a verification test of NAS batteries for wind power generation supplementation at TEPCO's Hachijojima Wind Power Station in fiscal 2001. This proved effective and led to the receipt in 2007 of a large capacity order for 34MW from Japan Wind Development Co., Ltd., a wind power generation firm. Japan Wind Development adopted the NAS batteries for the Futamata wind power site it was building in Rokkasho Village in Aomori Prefecture. Adoption of NAS batteries by wind power generation entities was given a boost by the Wind Power Generation System Support Measures Grant Project begun by NEDO in fiscal 2007[142]. NEDO decided to provide grants until fiscal 2012 for businesses that would newly construct wind power generators producing at least 2,000kW. The grants provide up to one-third of the installation cost of electric power storage facilities, such as NAS batteries, redox flow batteries, lead acid storage batteries, and lithium ion batteries[143].

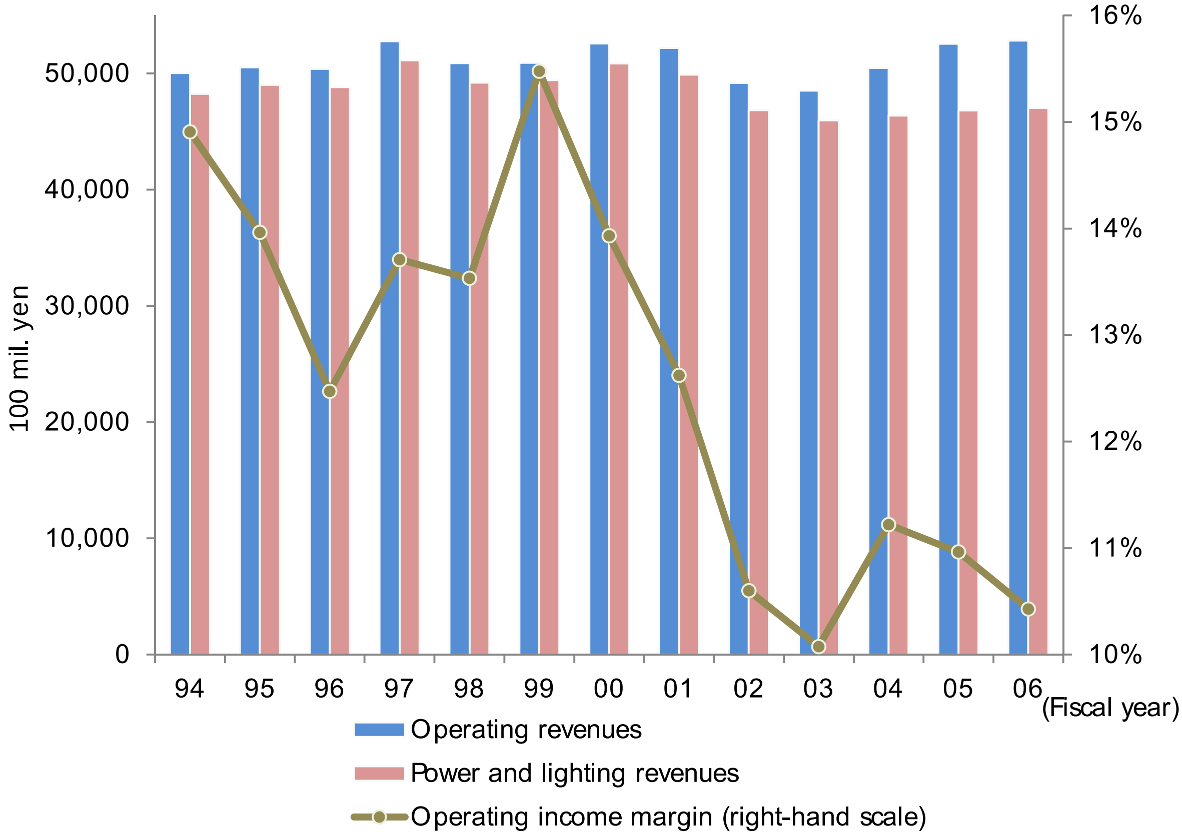
Owing to growing demand in overseas markets and for use to supplement wind power generation, NGK expects the NAS business to swing into the black in fiscal 2007. The company is planning to expand the area of its NAS battery plant, thus expand production capacity after fiscal 2008[144]. As of 2007, the NAS business accounts 13.6% of net sales of NGK's electric power-related business and 3.2% of net sales for the entire company as shown in Figure 10.

On the other hand, the influence of the operating results from TEPCO's NAS battery business on the company's total operating performance is difficult to gauge directly. Because TEPCO is an immense company with net sales in excess of five trillion yen, and its NAS battery business is so small for the company, TEPCO does not release the relevant information publicly. Therefore, we should try some other ways to assess the impact of NAS battery business on TEPCO's performance. We first look at the effect electricity liberalization had on TEPCO's operating results, and then roughly estimate the contribution of the NAS battery business against the effect under simplified scheme.

As highlighted in Figure 12, TEPCO's annual operating revenues had been around five trillion yen, of which about 90% is obtained from its domestic electricity business as shown by the revenues for power and lighting. Although not depicted in the graph, the ratio for the power business, which accounted for 97% of revenues until about fiscal 2000, has declined slightly in recent years. This reflects the progress of TEPCO's diversification into the information and communications business, the energy and environment business, best represented by liquefied natural gas (LNG), and the living environment and lifestyle-related business, including all-electric homes[145].

[141] Nihon Keizai Shimbun (January 30, 2007).
[142] Japan Wind Development Co., Ltd., FY2007-2010 Medium-Term Management Plan Materials (September 26, 2007).
[143] New Energy and Industrial Technology Development Organization (2007).
[144] Nihon Keizai Shimbun (January 30, 2007; October 4, 2007).
[145] TEPCO's Annual Report and the TEPCO Factbook (April 2007).

Figure 12. Change in TEPCO's operating revenues and operating income margin (consolidated), and revenues from power and lighting



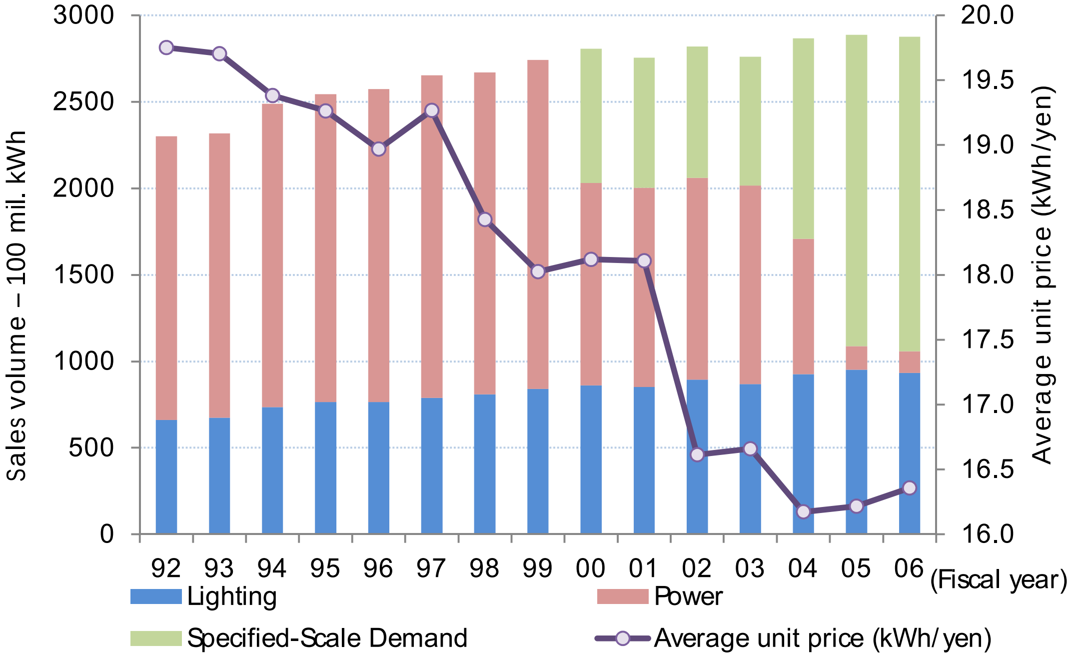
Note) Operating revenues by type of electricity contract are divided roughly into lighting used by small-scale users such as ordinary households and small stores, and electric power (high voltage) used by large-scale facilities such as office buildings, factories and mass merchandising stores. The sum for revenues from both types of contracts is used here.

Source) Prepared by referring to TEPCO'S Factbook (April 2007)

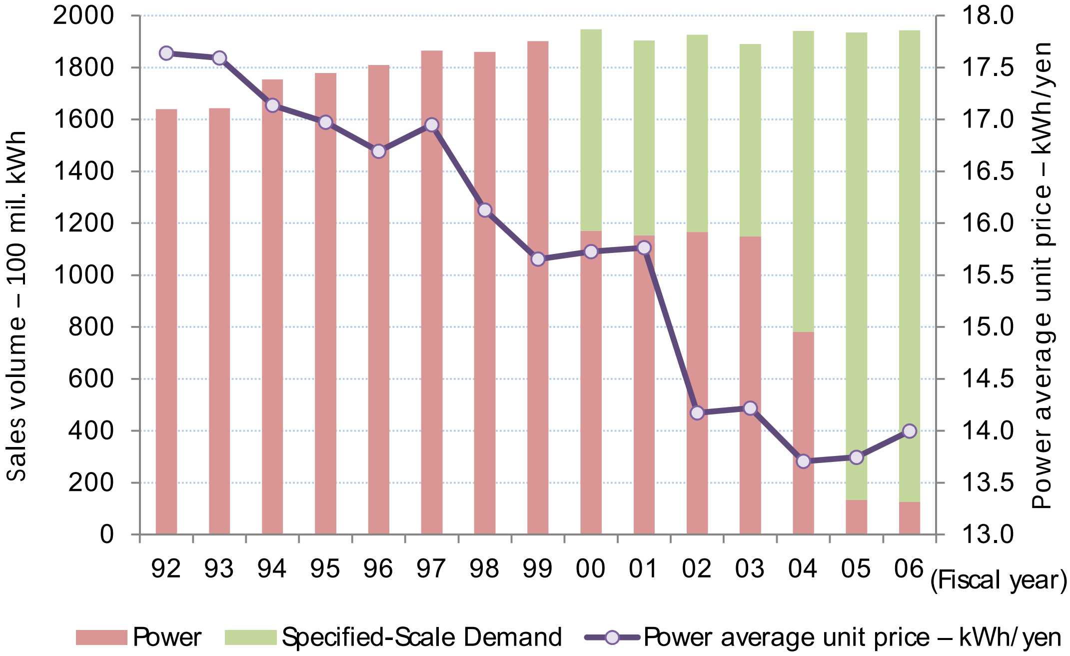
Moreover, as can be seen from Figure 12, power business income has decreased somewhat since fiscal 2001. Based on fiscal 2000, it dropped by 2% in 2001, and the decrease was about 8% afterward. The operating income margin can also be seen to trace a downward course since fiscal 2000 or the mid-1990s. Although lighting business revenue and operating income can vary depending on various factors, including the weather and socioeconomic conditions, we examine the effect of electricity deregulation here.

The change in TEPCO's lighting and power sales volume and change in average unit price, determined by dividing revenue by sales volume, are shown in Figure 13. Liberalization of electricity retailing has proceeded gradually expanding the scope of liberalization in Japan. For the beginning, large-scale customers who purchase 2,000kW or more were allowed to choose their supplier in 2000. The scope of liberalization was expanded in 2004 to include contracts of 500kW or more, and expanded again in 2005 to include contracts of 50kW or more. In 1995, private power generation was made possible by the deregulation of wholesale electric power (power generation), and after 2000 it became possible for customers to buy electric power from a new market entrant referred to as a Specified-Scale Electricity Utility (PPS: Power Producer and Supplier). In Figure 13(A), the volume of electric power sales to customers who were the target of electric power retail liberalization is classified as Specified-Scale Demand.

Figure 13. Change in TEPCO's lighting and power sales volume and average unit price



(A)



(B)

Note 1) Specified-Scale Demand is customers who were the target of electricity liberalization. The scope of liberalization was contracts for 2,000kW or higher (extra-high voltage) from fiscal 2000, 500kW or higher (high voltage) from fiscal 2004 and 50kW or more (high voltage) from fiscal 2005.

Note 2) The average in unit price (A) is the value calculated by dividing total power and light income by power and light sales volume (kWh). The power average unit price in (B) is the value calculated by dividing electric power rate income by electricity sales including Specified-Scale Demand (kWh), and does not include light contracted by ordinary households and small-scale stores, etc.

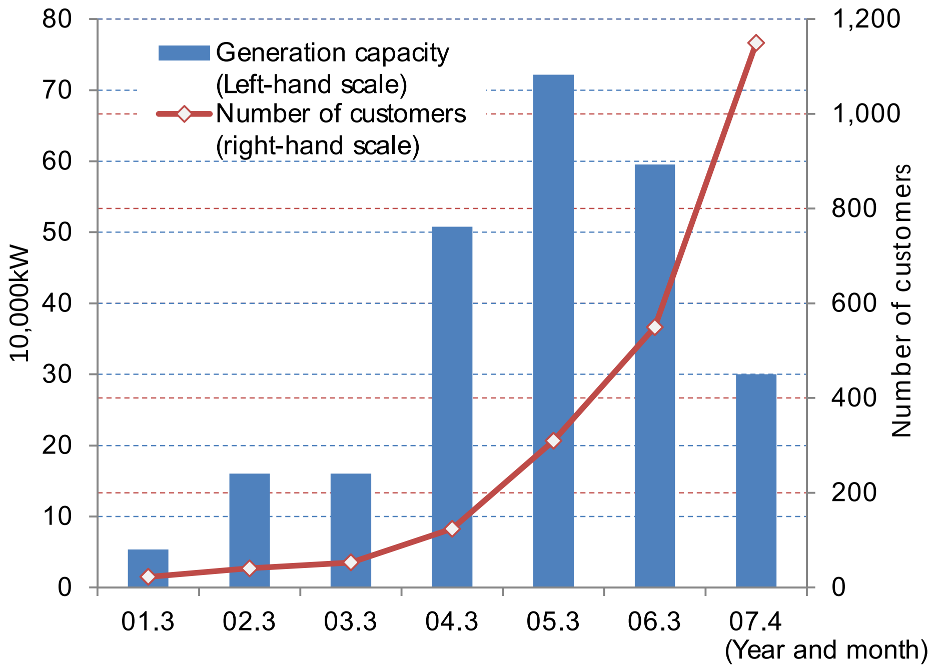
Source) Prepared by referring to TEPCO's Factbook (April 2007).

From Figure 13 (A) one can see the total volume of TEPCO's power and light sales has not decreased since fiscal 2000 but rather shows a marginal rise, and that the average unit price has declined since the 1990s, with a marked drop from fiscal 2002. The unit price, which was under 20 yen per kilowatt-hour in fiscal 1992, had fallen to 16.4 yen in fiscal 2006. The change in sales volume and average unit price for electric power excluding light, which was not subject to electric power retail liberalization, is shown in Figure 13 (B). This shows that while there was no great drop in electric power sales volume after fiscal 2000, the electric power average unit price has fallen from the upper 17 yen level per kilowatt-hour in fiscal 1992 to the upper 13 yen range more recently. Power utilities including TEPCO began lowering rates in response to the request of the government, which viewed the price differential between foreign and Japanese electricity rate in the 1990s as a problem, preparing for progress in electricity liberalization. Since the deregulation of electricity retailing in 2000, power utilities have striven to maintain customers by successive rate cuts, restraining capital investment[146].

Despite these efforts, however, some of TEPCO's customers terminated their contracts as a result of electric power retail liberalization. Since 2000 power utilities have continued to lose customers, and as of April 1, 2006, a total of 1,943 customers, with contracts for about 3.45 million kW of electricity, have switched their electric power purchases to PPS[147]. As competition with PPS is especially intense in TEPCO's jurisdiction, roughly 70% of the customers who switched to PPS until then are located in the area. According to the Agency for Natural Resources and Energy, PPS had a 4.14% share of the sales volume in TEPCO's jurisdiction in fiscal 2005[148]. The total number of customers who had switched from TEPCO to PPS by April 1, 2006 was 1,400, representing 2.4 million kW. This number has continued to increase since electric power retail liberalization, as shown in Figure 14. Because the competitiveness of PPS has weakened against the backdrop of the sharply rising price of fuel and the need to reduce CO_2, the rate of customer loss has seen a downward trend since fiscal 2005, viewed in terms of power generation capacity[149].

[146] Nihon Keizai Shimbun (December 29, 1995; February 9, 1998; April 2, 2002; August 10, 2006; March 26, 2007).
[147] Nikkei Sangyo Shimbun (May 11, 2006).
[148] Agency for Natural Resources and Energy, Advisory Committee for Natural Resources and Energy Electricity Business Subcommittee (2006).
[149] TEPCO Factbook (April 2007).

Figure 14. Change in number of customers who switched from TEPCO to a PPS and power generation capacity for said customers



Source) Prepared by referring to the Nikkei Sangyo Shimbun (February 16, 2006; May 11, 2006; May 10, 2007).

Against the customer loss resulted from electric power retail liberalization described above, what effect did the NAS battery business have? The impact of this business is not affirmative. By simplifying conditions, however, we can estimate some provisionally. Let us assume TEPCO was able to keep a customer from switching to PPS by installing NAS batteries at the customer within TEPCO's jurisdiction. As of September 2006, NAS batteries totaling 115,000kW were installed at 71 locations in TEPCO's jurisdiction. Moreover, as of April 2006, 1,400 customers with contracts for 2.4 million kW had switched their purchases from TEPCO to PPS. If we assume no additional customers switched their purchases between April and September, we can provisionally estimate the contribution of NAS batteries to customer retention as a little less than 5% in terms of both the number of entities and electric power capacity[150]. This estimation, however, has been made under a simplified framework that does not include privately generated and consumed power. Moreover, to consider the whole impact on TEPCO's operating results, we should observe the earnings from the company's NAS battery business itself, the effect of battery installation on substations, the effect on adapting to the RPS Law and the influence on TEPCO's overseas business, although they were not possible to observe.

As of 2007, few batteries for large-scale electricity storage other than the NAS battery have been commercialized on a mass production scale. Viewed from a functional aspect, however, various product technologies patently or latently compete with NAS batteries.

[150] Number of cases = 71 ÷ (71 + 1,400) × 100 ≈ 4.83%. Electric power capacity = 115,000kW ÷ (115,000kw + 2.4 million kW) × 100 ≈ 4.57%.

The first is cogeneration equipment, which is widely installed and is the strongest competitor if NAS batteries are viewed as a distributed power system. Superconducting magnetic energy power storage facilities[151] and redox flow batteries[152], which are in the verification test phase, could become direct rivals of NAS batteries provided they can overcome the issues of introduction cost and durability and are commercialized. Development of fuel cells for use in mobile phones, notebook computers and automobiles also is moving forward, and their use as an electric power storage facility is being attempted in the United Kingdom[153]. In addition, although their use for large-scale electricity storage is still considered difficult in terms of capacity as of 2007, Ni-MH batteries and lithium ion batteries, which are increasingly used for electronics products, are being developed by various entities as a power supply for electric vehicles[154]. Capacitors with their electricity accumulation function are being developed for railway systems and electric vehicles, and their use as a large-scale power storage facility or device to supplement renewable energy power generation is being considered[155]. As of 2007, despite the possible competition with those various product technologies in the future, the NAS batteries of NGK and TEPCO are expected to be popularized, since they are effectively the only high capacity battery for large-scale power storage that is being mass-produced and sold.

4. Conclusions

Finally, I would like to conclude this paper by discussing why commercialization of the NAS battery by TEPCO and NGK became possible. In terms of technology, NAS battery commercialization is attributed to three factors. First is the discovery of the basic principle by Ford Motor Company. This discovery of the basic principle became the starting point for all NAS battery development entities including TEPCO and NGK. Second is the establishment of a highly safe and durable basic structure by ABB. Although this basic structure was originally designed for electric vehicles, it was applied for electricity storage by TEPCO and NGK, producing significantly greater durability. Third is development of battery enlargement and mass production technology through the TEPCO-NGK project. This includes the development of various design and manufacturing technologies that vastly boosted economic efficiency while further improving durability and safety. Under the two companies' "continuity of commitment," it took 11 years from completion of the prototype to the start of mass production. Besides technological requirements, commensurate amount of demand and deregulation to permit installation were needed for commercialization.

Might we say the TEPCO-NGK project was able to acquire these factors because of a lucky break? As ABB withdrew from NAS battery development in 1996, it is seemingly a matter of good timing that the projects could introduce ABB's basic structure prior the

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151 Nihon Keizai Shimbun (August 9, 2005) and Nikkei Sangyo Shimbun (July 27, 2007).
152 Ueno (2005). Like the NAS battery, redox flow batteries are eligible for grants under the government's Advanced Load Leveling Equipment Introduction and Diffusion Model Project and Wind Power Generation System Support Measures Grant Project.
153 Nihon Keizai Shimbun (March 5, 2007; April 13, 2007) and Nikkei Sangyo Shimbun (August 29, 2001; April 20, 2007).
154 Nihon Keizai Shimbun (April 14, 2007; June 6, 2007).
155 Nikkei Sangyo Shimbun (January 23, 2006; July 3, 2007).

withdrawal. Conversely, NGK's aggressive overseas development became possible because ABB had withdrawn from NAS batteries as part of its business rationalization effort. Had ABB withdrawn earlier, its NAS battery technology might not have been reached, and if ABB had not withdrawn at all, NGK's overseas development might have faced greater hurdles. Moreover, just when realization of the scenario of replacing pumped storage power generation looked difficult, electric power liberalization moved forward and the demand for clean energy increased. Therefore the view that the timing was perfect might be possible. Electric power liberalization created a need for power utilities to counter the PPS and private power generation in Japan, while in other countries power utilities focused on controlling capital investment. Each country's government strengthened regulations to promote clean energy use, causing firms to position the reduction of CO_2 emissions volume as a key management challenge. Such changes in circumstances helped spur NAS battery demand. The situation competitors actively developed the battery and power utilities jointly took over the Moonlight Project's research, contributed to the relaxation of regulations on NAS battery installation. Pursuing this cooperation with other company might have been difficult, if the start of deregulation activity had been so delayed that other company terminated the development.

We could attribute NAS battery commercialization to excellent timing or fortune, if we only emphasize those points above. However, if we look into the matters, we will find causes and effects behind them. The deliberate decision taken at NGK to pursue the battery business led to NGK's technical tie-up with ABB and the establishment of Nastech. Management at both companies maintained support for the project over 20 years. Even when pumped-storage replacement scenario, the project's raison d'être, became difficult, they allocated the necessary capital and made efforts to find new one. As an indispensable condition, the deregulation of NAS battery installation required steady evidence of safety obtained through the continuous development activity and verification tests. Development of the mass production technology required an effort lasting 11 years. The ongoing commitment of the two companies led to the project's commercialization.

Why were the two companies able to maintain their commitment to develop the NAS battery business? For a project stretched over a long period due to its high difficulty of commercialization, as the NAS battery, the passage of time itself can be a major source of obstacles. Although ABB established an excellent basic structure for the NAS battery, it eventually withdrew when it came to need rationalization of business portfolio. In the same way, CSPL dissolved against the backdrop of electricity liberalization in the United Kingdom, in spite of their long-term development with U.K. and U.S. government support. Yuasa Battery turned its concentration on the lithium-ion battery following the New Sunshine Program, though it had actively continued NAS battery development participating in two national projects. In the earlier stages, other companies developing the NAS battery withdrew in succession, driven out by the technical difficulties as well as the change in various circumstances that accompanied the prolonged development period. Changes in the economic, social, and organizational environment are likely to alter the logic and significance of the development effort.

The TEPCO and NGK project also experienced various changes in circumstances as the development period lengthened. In NGK's electricity related businesses, the insulator business funding for NAS battery development began to shrink around 1993. During the 1990s, TEPCO cut down the cost widely and the R&D budget was reduced along with capital investment in preparation for the progress of electricity liberalization. As the construction and management costs of pumped-storage power stations gradually fell and annual load factors rose, voices indicating excess capacity began to be heard. To assert the significance of the NAS battery business and continue development, the product needed to be repositioned as other than an alternative to pumped-storage. While the advance of electricity liberalization and increase in demand for clean energy gave the project a new market opening, it made the cost target that had to be reached more difficult. In spite of these various changes in circumstances attended on prolonged development, why did the project continue to seek commercialization? Let us consider the reasons.

For both TEPCO and NGK, the other party's commitment was indispensable for carrying on with the project. For TEPCO, the basic battery structure from ABB that was eventually introduced by NGK was indispensable, and NGK's ceramics manufacturing know-how played a critical role for development of the mass production technology. But why did NGK maintain its commitment to the project? One possible explanation might be that TEPCO, which was a main customer for NGK's traditional business, used its position and exercised its power to compel NGK to maintain its commitment. While this might be plausible in the abstract, here I want to discuss a different explanation. On the one hand, NGK actually showed an initial intention to refuse TEPCO's request to participate in the project, and only decided to take part after being persuaded by Tsuneo Mitsui of TEPCO. However, within only a few years, NGK virtually declared it would get into the battery business beginning the technical tie-up with ABB. It appears that while the request from TEPCO gave NGK its NAS battery-related opportunity, NGK's continuation of the project and the way of involvement strongly reflected NGK's own intent.

NGK's ardor to diversify is explicitly the biggest reason it continued the NAS battery business development project. The company has proceeded to diversify its businesses from an early date in anticipation of the maturation of its insulator business, and each successive president had taken on new business development as a key mission. In addition, NGK was able to secure development funding until the long-term project neared commercialization. The Power Business Group under which the project was placed continued to grow until 1992, with rising revenues and earnings. When the power business lost momentum, growth in the engineering business and electronics business offset the slowdown, and after 2000 the ceramic products business that handles automobile exhaust filters grew rapidly. Along with its strong intention to diversify, NGK had the resource to endure and execute long-term development activities.

Moreover, the organizational position in which the NAS battery business development project was placed probably reflected NGK's aggressiveness toward the project, and it in turn strengthened its commitment to the project. The project was set within the Power Business Group, so-called "main stream" of the company. The electric power-related business was the business since foundation, centered on the insulator products for which NGK is named, and had long been dominant as a source of earnings. The NAS battery project might have been expected to overcome the maturation of the insulator business and revitalize the core electric power-related business. In addition, the organizational condition that ex-CEOs who decided active participation in the project remained NGK as a chairmen and advisors possibly had a positive influence on the project. Shunichi Takemi worked as company president of NGK until 1986, then filling the role of chairman until 1993, and advisor to NGK until 2002, besides served as vice-chairman of the Japan Federation of Employers' Associations and chairman of the NHK Board of Governors. Toshihito Kohara, who succeeded Takemi and worked as president until 1994, also served as chairman until 2002 and as an advisor thereafter.

Furthermore, until NGK established the NAS Battery Division, management itself led the NAS battery project. Noboru Yamamoto, who was head of the laboratory when the project was launched, also had the posts of executive director and R&D Division general manager. When he retired from these positions in 1987, Yamamoto held the positions of founding president of Nastech and technical advisor to NGK. Kokuji Kito, who was a director and deputy general manager of the Power Business Group, succeeded Yamamoto as president of Nastech in 1991. Kito had studied the status of NAS battery development, primarily in foreign countries, when NGK decided to participate in the project. Takashi Isozaki, who led the development team from the start of the project and was general manager of the NAS Development Department from 1990, had overall responsibility for the project after being promoted to director in the following year, and as a managing director became the first general manager of the NAS Battery Division in 1996. The organizational position in which the NAS battery business development project was placed reflected NGK's aggressiveness toward the project and is thought to have been contributed to resource allocation and continuity.

On the other hand, TEPCO's commitment was also indispensable for NGK. Along with being an important "prospective customer" for NGK's NAS battery business, TEPCO was a partner who provided development funds. As noted by NGK's Takemi, who decided the participation in the project, the relationship cultivated in the past with TEPCO through electric power components transactions reduced the development risk to NGK from the highly difficult NAS battery business. Not only the capital burden but also the provision of the verification testing locations by TEPCO, and the information the teams exchanged there, were no doubt effective for moving the development activity forward.

Why, then, TEPCO was able to maintain its commitment to the NAS battery project? For the start of the project to the latter half of the 1990s, the reasons were the obvious need for TEPCO to develop a means of storing electric power to replace pumped-storage, and a certain sense of mission that development by power utilities themselves was indispensable for the practical application. Because TEPCO is a huge enterprise with operating revenues around five trillion yen, TEPCO probably believed that it could manage the risk of highly difficult development together with the partner manufacturer.

When it entered the 1990s, however, TEPCO began to shrink its R&D budget along with its investment in plant and equipment expecting electricity deregulation to move forward. The problem of a gap between electric power rates overseas and in Japan garnered increased social attention in those days. Nevertheless, it continued allocating required resources to the NAS battery project for the reason that the project had been positioned as a technology that would help restrain capital investment. Moreover, as the scenario of replacing pumped-storage became difficult, commercialization of the project was achieved by redefining its position taking advantage of deregulation. The new position was a product to retain customers and defend TEPCO's existing business. The allocation of resources to the project and change in the project's positioning were supported consistently by the management like Gaishi Hiraiwa.

Hiraiwa, who decided to begin the NAS battery project at TEPCO, assumed the position of chairman in 1984, and after retiring chairman in 1993, served as an advisor to TEPCO until 2007. Besides taking on duties outside the company, including a stint as Nippon Keidanren chairmen, he looked upon the project as TEPCO chairman and advisor. In addition Tsuneo Mitsui, who as managing director in charge of TEPCO's Engineering Research & Development Division persuaded NGK to participate in the project, worked as director and general manager of the Research & Development Center from 1986 to 1991 and served as Senior Executive Adviser to TEPCO afterwards. At TEPCO as well, the position of the NAS battery business development project within the organization is thought to have had an influence on resource allocation and continuity.

If we focus on the relationship between TEPCO and NGK, the NAS battery project was a joint development by a manufacturer and a prospective customer that grew out of a buyer-seller relationship of electric power materials based on insulators. Therefore withdrawal by TEPCO would have meant the loss of a prospective customer and greater development risk for NGK, and withdrawal by NGK would have meant sunk cost amounted to billions of yen for TEPCO. For both companies, this project was in some ways a fated partner relationship, and prolonged development period may have further strengthened the two firms' commitment. Moreover, the relationship of little distrust or miscommunications, the two firms had constructed through their long-term transactions, likely to have positive influence on the project's outcome. Distrust or miscommunications might obstruct the joint development activity. Through their long-term transactions for insulators and other electric power materials, TEPCO and NGK had fostered understanding and trust concerning each other's technical capabilities, know-how and corporate culture. Since two companies' development teams with such a relationship communicate frankly to solve problems in the repeated verification tests, the development activity made good progress.

Finally, strong intent of the project to commercialize the business, at the very outset and throughout the process, was definitely critical for the outcome. The intent of commercialization was reinforced by NGK's decision to diversify into the battery and the progress of electricity liberalization in Japan. We might say the joint development organization of the two companies was in marked contrast to the joint development system among multiple firms in the Moon Light Project and other national programs. Unlike TEPCO and NGK, it might have been difficult for national projects under the framework set by the government to introduce technology outside the project or change established division of labor. While development risk can be mitigated with government support in a national project, well-devised design of framework will be required to maintain flexibility like that seen in the TEPCO and NGK project .

Moreover, even when the goal of development is set to practical level, national projects typically do not seek commercialization through cooperation among the participating firms. Companies that engage in joint development under a national framework are basically in a temporary cooperative relationship, but are not business partners. To make exact comparison, we should further inquire into the detail of communication between batteries manufacturers and power utilities which provided verification test locations in the Advanced Battery Energy Storage System development project under the Moon Light Project. Unlike the TEPCO and NGK project, however, that national project fundamentally was not a joint development activity set for joint commercialization. Since national projects do not assume commercialization in general, the participants do not necessarily strive by all means to commercialize the technology they take charge of in the projects. On the contrary, companies can be even possible to participate in national projects just as a way to assess the potential of one of alternative technologies, thereby reducing risk to commit “unpromising” one[156]. Even for the TEPCO and NGK project, we can think that the development risk was partly reduced in the form of NGK and Hitachi competing for the results. The TEPCO and NGK project, however, had been sticking to commercialize NAS battery. Although various changes in circumstances cause other development entities terminate or reduce development efforts, both companies maintained their efforts.

[156] The case of Yuasa Battery and Kansai Electric Power Co., Inc. may provide some insight regarding this argument. On the one hand, they engaged in NAS battery development in the Advanced Battery Energy Storage System development project under the Moon Light Project. On the other hand, according to Nobuyuki Tokuda, chief researcher (at the time of 1995) at the Energy R&D Laboratory of Kansai Electric’s Technical Research Center, Kansai Electric evaluated various new batteries independently of the Moon Light Project and found out that the redox flow battery would be a promising electricity storage technology able to compete with pumped-storage power stations. Consequently, it began joint R&D of this battery with Sumitomo Electric Industries, Ltd. from 1985, separately from the Moon Light Project (Tokuda, 1995). According to Ueno (2005), this joint development was continuing as of 2005, with verification tests aimed at practical application. Moreover, despite its active development of the NAS battery from an early stage through two national projects, Yuasa Battery turned the development focus to lithium ion batteries in the 1990s, perhaps continuing some effort on NAS battery. In the 1990s, as lithium ion battery came to be seen as a sort of promising technology for electricity vehicles and smaller scale electric storage, it was selected by the government to develop under the New Sunshine Program (Nikkei Sangyo Shimbun, July 28, 1990, December 19, 1990, March 16, 1993, October 7, 1998, April 21, 2000). Since Yuasa’s main business is rechargeable batteries for automobiles and manufacturing use, it also was active in improving traditional lead acid storage battery technology and developing polymer batteries, fuel cells and Ni-MH batteries, in addition to lithium ion batteries (Nikkei Sangyo Shimbun, July 18, 1989; May 16, 1994; February 12, 1995; April 14, 1996; August 3, 1998; March 24, 1999; September 26, 2001; November 7, 2001; December 24, 2004; November 8, 2005).

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