Is public R&D in energy efficiency really effective? – A case in Japan and its implications

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Keywords

public R&D; effectiveness; commercialization; diffusion; governmental support

Abstract

In order to achieve an energy-efficient economy, the government has been intensifying investment in research and development (R&D) of energy-efficient technologies. But, are public R&D programs really effective in developing innovative energy-efficient technologies? How many technologies developed in these programs have succeeded in commercialization? What are the key factors for successful commercialization and diffusion in the market? This paper tries to answer these questions by examining Japanese experiences, focusing on two major R&D projects in energy-efficient technologies that were conducted from 1984 to 2000 by the government. The analysis found that of the 34 technologies developed in the two projects only seven have been commercialized so far, four of those seven have only a very limited number of installations, and only one has a growing market. Based on the analysis the paper shows that: while public R&D investments have high risk of failure, they can bring new technologies after a certain lead time at a reasonable probability of success; the governmental R&D support should be stable and long-term to enable continuous private investment in risky technology; and technology-specific support by the government can be effective when designed to support each stage of technology development from basic research to wider diffusion.

Introduction

In order to achieve an energy-efficient economy, the government has an important role to accelerate research, development, and deployment (RD&D) of energy-efficient technologies. While it is an essential role for the government to promote deployment of beneficial technologies that are already on the market, it is also important to stimulate research and development (R&D) to supply new, innovative technologies.

Responding to this important need, developed countries have been investing large public budgets into energy R&D in order to reduce oil dependence and carbon dioxide emission. According to IEA estimation, IEA member countries spent a budget of 10.9 billion USD in energy technology R&D in 2006, of which 1.2 billion USD was for energy efficiency R&D (IEA 2008). Among those countries Japan with the US is ranked the largest investor, spending 3.6 billion USD in total, of which 448 million USD for energy efficiency in 2006. This indicates that about one third of public R&D in energy efficiency in IEA member states was funded by Japan.

In spite of the high expectation for and large input in energy R&D, there still exists an obvious question "Is public R&D really effective?" Although numerous studies have shown substantial benefits associated with publicly funded research (Georghiou, 1999; Georghiou & Roesnner, 2000; Salter & Martin, 2001), only a limited number of publications examined the effectiveness of applied energy R&D empirically[1]. There is almost no empirical assessment regarding Japanese R&D programs in the energy field. Considering the high share of Japanese public R&D in energy efficiency, it is important to investigate the

1. Notable exception is NRC (2001), which assessed the costs and benefits of applied energy R&D by US Department of Energy (DOE).

Japanese experience which might have useful implications for policy makers. The objective of this paper is therefore to assess the effectiveness of public R&D as a policy instrument to increase energy efficiency, and to induce some lessons learnt for managing R&D. The research questions covered in this paper are:

1. What is the outcome of public R&D in energy efficiency? Has it produced any commercialized technology?
2. If there are energy-efficient technologies being commercialized as a result of public R&D programs, how did they emerge? What were the key factors behind their successful commercialization?

In order to answer these questions, the paper aims to do two things: first to investigate *how many* technologies were commercialized through the NEDO (New Energy and Industrial Technology Development Organization) projects, and second to analyse *how* these were commercialized and finally explore the key factors for successful commercialization. "Commercialization through a program" here refers to the evolution of a technology under an R&D program into a major part of a commercial product available in the market (i.e. not for demonstration purposes).

It should be noted that public R&D programs are usually expected to have broad kinds of effects not limited to direct commercialization. These effects include: expanding private R&D activities; forming networks among university researchers and industrial experts; increasing the stock of useful knowledge; creation of new scientific instrumentation and methodologies; increasing the capacity for scientific and technological problem-solving (Salter & Martin, 2001; Ruegg & Feller, 2003; Lee et al., 2003). Since the objective of this paper is to assess the effectiveness of public R&D as a policy instrument for higher energy efficiency, the focus is on the direct outcome of public R&D programs, i.e. commercialization of innovative energy-efficient technology from the program. Other benefits from public R&D programs, although important, are out of the scope of this study due to time and resource constraint.

Background and the case of this study

ENERGY CONSERVATION IN JAPAN

Japan has been heavily dependent on imported primary energy sources because of scarce domestic resources and growing energy demand. The oil crises of the 1970s had a tremendous impact on Japan's economy because it was highly dependent on foreign oil in the early 1970s. Around that time, more than 70% of the primary energy was imported from the Middle East. This made energy security as one of the top issues of the nation, and the government initiated various measures in order to decrease foreign oil dependence. The major focus was on increasing supply mainly from coal and nuclear power. The government also established the *Sunshine Program* in 1974, which was an R&D program for developing renewable energy and alternative fuel technologies aimed at expanding domestic energy sources in the long term. Energy conservation was one of, if not the most, important issues in the policy response against the oil crises. Since the projected energy supply could fall below the increasing demand if no measures were taken, the government introduced various regulatory measures, such as the *Energy Conservation Law*, as well as subsidy programs in order to reduce energy demand and stimulate energy efficiency investments (MITI, 1975).

JAPANESE PUBLIC R&D IN ENERGY EFFICIENCY

In addition to these measures, the government launched a new R&D program in 1978, which was called the *Moonlight Program*, to develop new energy efficiency technologies that could realize a drastic reduction in energy consumption in the future. This program and the Sunshine Program were integrated into the *New Sunshine* Program in 1993, which continued until 2002. Managed by NEDO, a subsidiary organization of the Ministry of International Trade and Industry (MITI), these programs had provided stable funding for renewable energy and energy efficiency R&D for more than 20 years. R&D costs of these programs were fully covered by NEDO, and more than 120 private firms participated in these programs (Watanabe, 1999). In most cases, either private firms or industry associations were the main recipients of funding, while national research institutions and universities also joined and collaborated. Among the two program areas in energy efficiency R&D – supply-side energy efficiency and demand-side energy efficiency –, the demand side was only a minor focus in several projects. R&D projects conducted under the Sunshine, Moonlight and New Sunshine programs are summarized in Table 1.

HEAT PUMP AND WASTE HEAT UTILIZATION PROJECTS

Two projects in demand-side energy efficiency, *the Super Heat Pump and Energy Accumulation Project* (1984-1992) and *the Eco Energy City Network Project* (1993-2000) were chosen as case studies in the paper. The first reason for this choice was that they both address topics that are major concerns in demand-side energy efficiency in Japan, i.e. development of more efficient heat pumps, waste heat recovery systems, and heat transportation and utilization technologies. Since they were managed consistently by NEDO in order to provide continuous support for R&D activities concerning development of new energy efficiency technology in heat utilization, it is deemed appropriate to consider these projects together as the subjects of the case studies. The second reason was that the two projects, being terminated for more than 10 years or so, are old enough to observe their outcomes that emerged years after their termination. Considering the long lead time before energy R&D investments result in output on the market (Margolis & Kammen, 1999), this is an essential condition for this study. Research topics conducted under the two NEDO projects are listed in Table 2.

How many technologies addressed by the two projects have been commercialized?

METHOD

In order to investigate *how many* technologies have been commercialized through the NEDO projects, the development status of each technology addressed by the projects was tracked down and confirmed by conducting interviews and literature survey. Companies who joined the projects were asked if there was

Table 1. Energy R&D under the Sunshine, Moonlight, and New Sunshine Programs (1974-2002)

Project	Period	Public funding [million USD] [1]
Renewable energy		
Solar	1974-2002	1,740
Wind	1981-2002	77
Geothermal	1974-2002	655
Alternative fuels		
Coal liquefaction	1974-2001	2,146
Coal gasification	1974-2002	942
Supply-side energy efficiency		
Hydrogen and fuel cells	1974-2002	953
Advanced gas turbine	1978-1987	249
Ceramic gas turbine	1988-1998	87
Stirling engine	1982-1987	64
MHD power generation	1978-1983	36
Superconducting technologies	1988-1999	230
Advanced NaS battery	1980-1991	145
Demand-side energy efficiency		
Advanced Li-ion battery	1992-2001	147
Future electron devices	1998-2002	49
Super heat pump	**1984-1992**	**61**
Eco energy city network	**1993-2000**	**73**

Note. *Budgets are in 2002 price and exchange rate. Source: NEDO (2000)*

Table 2. Technologies developed under the heat pump and waste heat utilization projects

Super Heat Pump Project	Eco Energy City Network Project
Heat pump	*Waste heat recovery*
(1) High efficiency heat pump (high-temperature type)	(16) Heat recovery from slag process in steel plants
(2) High efficiency heat pump (dual type)	(17) Distillation column with internal heat exchange
(3) High output heat pump for low-temperature heat source	(18) LNG cold heat utilization technology using hydrogen absorbing alloy
(4) High output heat pump for high-temperature heat source	(19) Thermoelectric generating system using low-calorie exhaust gas
Cooling medium	(20) Thermoelectric generating system using low temperature waste heat
(5) non-alcoholic mediums for high output heat pump	(21) Waste heat recovery system using latent heat in exhaust gas
(6) alcoholic mediums for high-temperature output heat pump	*Heat transport and storage*
Heat exchanger	(22) Heat transport system using methanol decomposition and synthesis
(7) Stainless steel plate-fin heat exchanger	(23) Heat transport system using hydrogen absorbing alloy
(8) EHD heat exchanger	(24) High efficiency heat pump using hydrogen absorbing alloy
(9) Evaporator for mixed refrigerants	(25) Heat transport system using vacuum insulation
Chemical thermal storage system	(26) Heat transport system using surfactant
(10) Thermal storage using clathrate reaction	(27) Heat transport system using clathrate hydrate slurry
(11) Thermal storage using hydration reaction by solute mixing	*Heat pump*
(12) Thermal storage using hydration reaction	(28) High efficiency heat pump using multi-fuel gas engine
(13) Thermal storage using ammonia complex	(29) Compression/absorption hybrid heat pump
(14) Thermal storage using solvation reaction	(30) Absorption chiller using waste heat
(15) Thermal storage using metathesis reaction	(31) Bidirectional thermosyphon heat pipe
	(32) Absorption pump using natural refrigerants
	Others
	(33) Flux measurement for contaminated fluid
	(34) Cold heat supply system using microsphere

Note. *Numberings and English translation by the author. Source: NEDO (1993), ECCJ (2001, 2007)*

Table 3. Technologies commercialized from the NEDO projects

Technology	Participant	Status of commercialization
(1) High-efficiency heat pump (high-temperature type)	Ebara Corp.	1 plant was adopted for regional cooling and heating
(2) High-efficiency heat pump (dual type)	Kobelco	More than 40 systems were sold as "Ultra High-Eff" after joint development with Chubu Electric Power Company. "High-Eff Mini", a succeeding product, sold about 700 systems (2007)
(7) Stainless steel plate-fin heat exchanger	Sumitomo Precision Products	Stainless steel plate-fin type heat exchanger using vacuum brazing technology was established in the project, which was adopted in fuel cells and micro gas turbine systems (Installation number was undisclosed).
(10) Thermal storage system using clathrate reaction	Mitsubishi Heavy Industry	10 were sold as clathrate thermal storage systems after development of alternative refrigerants.
(23) Long-distance heat transport system using hydrogen absorbing alloy	Japan Steel Works	4 were sold as waste heat chiller systems with hydrogen absorbing alloy.
(27) Heat transport system using clathrate hydrate slurry	JFE Engineering Corp.	9 were sold as air-conditioning systems using clathrate hydrate slurry. More than 20 systems are under consideration for installation.
(30) Absorption chiller using waste heat	Hitachi	14 were sold mainly in ESCO projects as absorption chillers with mixed refrigerants of water-lithium bromide.

Note. *Numberings the same with Table 2.*

any commercialization resulting from the projects. For 17 out of the 34 technologies developed in the projects, responsible people familiar with the development status of the respective technologies were identified in each participant company, which resulted in 20 interviews. For the other 17 technologies neither the author nor the participant companies could identify any suitable person in the company because of reasons such as transfer of responsible personnel or reorganization of the company. For those 17 cases additional interviews were conducted with four experts who were in the position of coordinating the projects and knew the development status of the technology very well, and three researchers who have been conducting related research during the same time period and know if there was any commercialization of these technologies. In addition, literature survey was conducted to reconfirm interview data.

RESULT

After the investigation, it was found that seven out of the 34 technologies addressed by the NEDO projects had some forms of commercialization. The status of commercialization of the seven technologies is summarized in Table 3. It was also found that another technology, distillation column with internal heat exchange (No. 17), is the subject of another NEDO project for commercialization and is very likely to come to the market in the next few years. As for the other 26 technologies, there was no commercialization.

The reasons behind the non-commercialization were diverse and complex, and in many cases it was impossible to identify them due to lack of data. Some of the reasons found in this study include regulatory change (i.e. phasing out of the use of CFCs; No. 8), long pay-back period (No. 16, 24, 26, 29), technical barriers (No. 19, 20), organizational restructuring (No. 24, 25), and stagnation of related markets (i.e. cogeneration systems could be a favourable source of waste heat for the technology but the market did not expand as expected after the late 1990s; No. 29, 32).

The result that the majority of the technologies developed in the NEDO projects failed in commercialization clearly shows the high-risk nature of public R&D projects in energy efficiency. But at the same time, the result also indicates the effectiveness of public R&D projects, i.e. at least seven out of 34 were commercialized.

Table 3 also shows that, even in the 7 cases of successful commercialization, market diffusion may still be limited. Except for super-efficient heat pumps (No. 2) with sales in the hundreds, the number of installations is quite low, ranging from 1 to 14. While the stainless steel plate-fin heat exchanger (No. 7) and the heat transport technology with high thermal density (No. 27) are still expanding their markets, other commercialized technologies (No. 1, 10, 23, and 30) have no expectation of further market growth[2]. The major reasons of limited diffusion include the stagnation of related markets (i.e. district heating and cogeneration; No. 1, 23, 30) and unfavourable economics compared to competing technologies (No. 1, 10, 23, 30).

This point can be understood more clearly by using two concepts, Valley of Death and Darwinian Sea, adopted from the literature on technology management (Branscomb & Auerswald, 2001, 2002). The term "Valley of Death" describes the challenges facing entrepreneurs engaged in the transition from basic R&D to innovation. Following this concept, Branscomb and Auerswald proposed the term "Darwinian Sea" as a more appropriate image, which illustrates "*a sea of life and death of business and technical ideas, of big fish and little fish contending, with survival going to the creative, the agile, the persistent*" (Branscomb & Auerswald, 2002: 35). Although the two concepts basically point to the similar difficulties in early-stage technology development, it is useful to directly connect them as different challenges in the process, as proposed by Wessner (2001). This idea is shown in Figure 1, where basic R&D has to cross the Valley of Death before reaching a "new business" phase, after which there lies the Darwinian Sea with various competing technologies to be defeated before evolving into

2. The last installations of No. 1 and No. 10 were in the 1990s, and those of No. 23 and No. 30 were in 2001 and 2004. Since then no further adoption was occured for those technologies

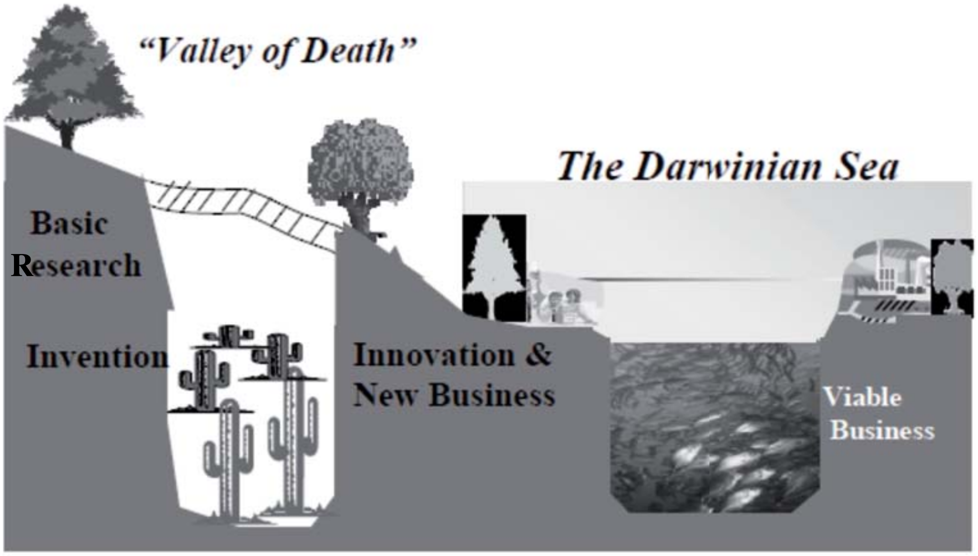

Figure 1. The Valley of Death and the Darwinian Sea in innovation process (adopted from Wessner, 2001).

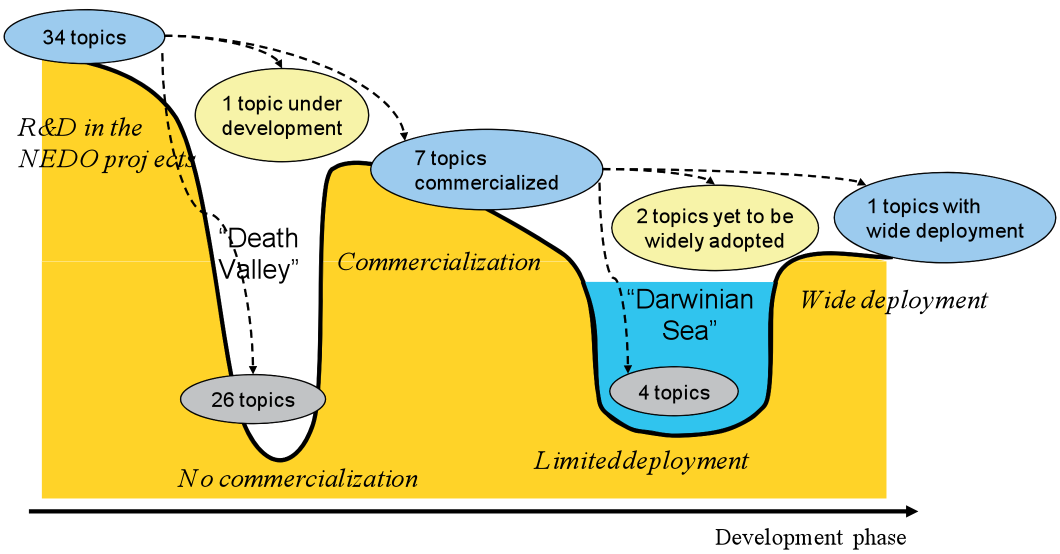

Figure 2. The Valley of Death and the Darwinian Sea in the commercialization process from the two NEDO projects.

a viable business[3]. Based on these concepts, the development status of the 34 technologies within the two NEDO projects can be described in Figure 2. Of the 34 technologies, only 7 reached commercialization (crossed the Death Valley), 1 is still under development (trying to cross the Valley), and the other 26 were trapped in the Valley. In addition, of the commercialized 7 technologies, 4 have only a limited number of installations (drawn in the Darwinian Sea), 2 are still waiting to be widely deployed, and only the remaining 1 has an already growing market (became a viable business). This framework is thus valuable in that it can distinguish the success or failure in commercialization from those in wider diffusion resulted from public R&D.

It should be noted here that non-commercialization does not necessarily mean a "failure". Indeed in many cases of non-commercialization, interviewees acknowledged the existence of other benefits from the projects (e.g. forming technological base that could be applied to other products; increasing the stock of scientific knowledge). For example, Maekawa MFG Co., which conducted the development of high output heat pump for low-temperature heat source (No. 3), admitted that while they did not directly commercialize the technology from the NEDO projects it was extremely beneficial to expand their technological capacity and apply it to improving their industrial heat pump products.

3. "Crossing the valley of death only to arrive in the Darwinian Sea" (Wessner, 2001).

What were the key factors for successful commercialization?

METHOD

In order to analyse *how* commercialization was achieved, two technologies with the most successful commercialization, No. 2 and No. 27, were selected as cases to be studied. Due to the explorative nature of the case studies, in-depth interviews were conducted. For each case, two to three of the engineers and managers who had been closely engaged in developing and commercializing the technologies, were identified and interviewed. Questions used during the interviews focused on the following topics:

- history of related R&D activities within the company before the NEDO project was started;
- reason why the company decided to join the NEDO project;
- factors that were of importance in commercializing the technology;
- importance of the NEDO project for commercialization.

Information gained during the interviews was supplemented by literature, including press releases and technical reports by the firms. The following section describes the commercialization process of the technologies, after which the factors for successful commercialization are summarized.

CASE 1: DEVELOPMENT OF HIGH-EFFICIENCY HEAT PUMP BY KOBELCO (NO. 2)

Background and the NEDO project

Kobelco is one of the largest steel manufactures in Japan. The company is also a major manufacturer of various metal products and has had a high technological competence and market share in compressors since the 1960s. The company joined the Super Heat Pump Project of NEDO in 1984. The technical target of the project was to develop a heat pump system with a cooling efficiency of coefficient of performance (COP) [4] more than 7 (for 32°C heat source and 7°C output), and heating efficiency of COP larger than 6 (for 10°C heat source and 45°C output). This was a very ambitious target given the technology level in the 1980s. This high efficiency target required the adoption of an alternative heat cycle, which is called the Laurent cycle. While it was known that the Laurent cycle, using mixed refrigerants, was theoretically more efficient than the usual Carnot cycle, there had been no practical application previously due to technical difficulties.

As there were various technical as well as market uncertainties facing the development of such an innovative technology, the task was highly risky for Kobelco. Interviewees admitted that in the beginning there was little expectation for the technology being put into practical use and that it would have been impossible without NEDO funding. In fact, some engineers even thought that the project was wasting time and money as it was a very risky technology.

The follow-up project

The technical targets were eventually achieved and the project was terminated in 1992. Even though Kobelco mastered the Laurent cycle through the project experience, the technology was not promising at all. In terminating the project NEDO requested power companies to follow-up on the development. The Chubu Electric Power Co., which was working on various R&D related to energy conservation and load management, responded to NEDO's inquiry and started a joint project with Kobelco to continue the development of the high-efficiency heat pump.

Although the heat pump system developed in the first NEDO project was almost twice as efficient as conventional ones, it had serious problems for practical use. For example, its heat exchanger became too huge to install in order to achieve the high efficiency target, and was made of aluminium, making it corrosion-vulnerable (Watanabe, 2004). As a result, an improved heat pump system was developed during the joint project. It was 1.5 times as efficient as conventional ones, and achieved its technical target in 1995 (Watanabe et al., 1996).

Commercialization

When the follow-up project was successfully terminated in 1995, there was still no prospect for commercialization due to its large installation space and very high initial cost. But, when the project was being terminated, an aquarium expressed its interest in the system. Due to the potential market demand, Chubu Electric and Kobelco decided to continue development for commercialization (Watanabe, 2004). Around that time the technology of plate-fin heat exchanger went through a considerable improvement, which made it possible for the heat pump system to be efficient, compact, durable and much cheaper at the same time.

Finally, in April 1999, Kobelco and Chubu Electric released the high efficiency heat pump as a product named "Ultra-High Eff(iciency)". It was about 1.5 times as efficient as conventional heat pumps, although had a cost almost twice as much. It was firstly adopted by the aquarium as well as a few large companies as air conditioners. These companies valued the high efficiency and environmental performance much more than economic factors, and became "early adopters". Based on the high reputation by the early adopters, it was sold much more than expected, with installations reaching 40 by December 2001 (Chubu Electric & Kobelco, 2001).

Development of a successor product

The Ultra-High Eff thus successfully captured the initial market. But as the problems in terms of space, weight, and price were still remaining, it turned out to be difficult to further increase its sales. Decrease in efficiency at partial load operation was also a problem. Facing these problems, Kobelco and Chubu Electric with two more power companies developed an improved product, which was called "High Eff Mini". The major improvement was its high cost-performance achieved by introducing inverters and better plate-fin heat

4. The ratio of heat provided/removed in watts per watt of energy input

exchangers. Kobelco also reduced production models from six to two for cost reduction. This was particularly important because having a wide range of models, from 570 to 3300 kW, kept the prices high. The company limited the supply in the middle-range capacities, 300 and 500 KW, where there were only a few competing heat pumps with high-efficiency[5]. By these measures the price was reduced almost 40% from that of the original Ultra High-Eff, although the efficiency declined a little from the previous level.

With these developments the High Eff Mini was released in March 2003. It soon earned reputation for its high efficiency and high cost-performance, and had already sold about 700 systems by 2007. Kobelco and the three power companies further developed a smaller version of High-Eff Mini called "High-Eff Heat Pump" in 2006. At present, both products are eligible for an investment subsidy by NEDO, through which adopters can receive a subsidy up to one third of the price difference between these new and the conventional technologies.

CASE 2: DEVELOPMENT OF HEAT TRANSPORT SYSTEM USING CLATHRATE HYDRATE SLURRY BY JFE ENGINEERING CORP. (NO. 27)

Background

JFE Engineering is the engineering branch of JFE Steel Group, one of the major steel manufacturers in the world. Since improving energy efficiency in steel mills has always been an important task for the company, it had started researching heat mediums with higher thermal density, including clathrate hydrate, in order to increase energy efficiency in the oxygen production process before the NEDO project took off. In order to expand their businesses outside their steel mills, the company wanted to broaden the applications of the heat mediums. So the R&D division of the company proposed an air conditioning system using clathrate hydrate as the heat medium to achieve higher efficiency. Since this proposal was too risky to conduct on their own, they demanded public funding from NEDO and proposed it to its Eco Energy City Network project. In 1997 their proposal was adopted as one subject in heat transportation technologies.

The NEDO project and its follow-up project

In the NEDO project various clathrate hydrates were tested and a small testing system was constructed. It was shown that the proposed system could reduce energy consumption in air conditioning by around 50%. The hydrate slurry production equipment was also improved by adopting commodity type plate-fin heat exchangers, which reduced system cost even further (Nikkan Kogyo Shinbun, 2006).

As the results of the project seemed promising, JFE Engineering decided to conduct a demonstration project as a next step towards commercialization. But it was conceived too risky to carry all the costs of constructing demonstration plants, so the company applied to another NEDO commercialization program. Their application was adopted with a subsidy of 50% of the costs. This made it possible for the company to construct two demonstration systems, one in a factory of Hitachi and the other in a building of Takenaka Corp., a major construction company in Japan. The demonstration tests were of critical importance for establishing the design technologies and control technologies.

Throughout the two projects JFE Engineering received public R&D funding of about 500 million Japanese Yen (3.8 million Euro[6]). Without this public support it would have been impossible for the company to start and continue the development, even though it has invested more than three times of the subsidy amount in the development so far.

Commercialization with investment subsidy

The first application of clathrate hydrate slurry as an air conditioning system was installed in the new main building of Takenaka Corp. in 2004. Takenaka, as a highly environmentally conscious company, adopted various innovative energy efficiency technologies in the new building, and the heat transport system was one of them (Takenaka Corp, 2004).

In 2005 JFE Engineering established the marketing division of the system. By 2008 they had already sold seven systems and two more are planned to be sold, despite the payback time of additional costs compared to conventional ones being more than five years (JFE Engineering, 2005, 2007). Reasons behind this success were the environmental consciousness of adopters who valued high energy efficiency more than economic factors, and the availability of investment subsidies provided not only by NEDO but also by the Ministry of Environment and other organizations. In fact, all of the nine installations received some kind of subsidy to shorten the payback time.

SUMMARY: FACTORS FOR SUCCESSFUL COMMERCIALIZATION AND DIFFUSION

The two case studies revealed a variety of factors that influenced the commercialization and diffusion of the two technologies. The major factors can be summarized as follows:

1. Public R&D was indispensable in the commercialization of the technologies. Although developments were based on the companies' stock of technologies, these would have been very difficult to even initiate without the R&D projects of NEDO due to their high-risk nature. This in turn indicates that public R&D projects have successfully enhanced private R&D in innovative, but high-risk, technologies that had little expectations of being commercialized.
2. Follow-up projects that were supported by external organizations have played an essential role in continuing the development of technologies (the joint project with power companies in Case 1, and the NEDO follow-up project in Case 2). In both cases the technology required seven to 15 years from the initiation of the project to reach commercialization. It would have been very difficult for the companies to continue financing high risk technologies for such long periods of time without external financial support.
3. Marketing and finding the right customers were important factors in commercializing new technologies. In both cases

5. As for both smaller heat pumps (i.e. residential air conditioner) there are numerious competing companies. For larger ones another type of heat pumps using turbine compressors, not screw compressors like Kobelco's ones, have an advantage.

6. Based on 130 JPY/Euro exchange rate.

there were a few users who put high value on innovativeness or environmental friendliness of the technologies which at first were much more expensive than conventional technologies. These are innovators or early adopters in the diffusion process of the technology (Rogers, 2003), and form the initial market on which the developers can expand their marketing activities.

4. A diffusion strategy can play a decisive role in expanding the initial niche into a larger market. In Case 1, the developers not only improved the performance of the technology but also focused their production into the market segment in which they had a strong advantage over competitors. They also took a balance between performance and cost, as they reduced the production cost at the expense of efficiency. In order to achieve wider diffusion beyond a limited number of initial adoptions, these kinds of marketing efforts proved to be indispensable. Without such efforts, the heat transport technology we examined in Case 2, for example, would likely not diffuse any further than the initial niche at the moment.
5. Investment subsidy was another important policy measure to promote early-stage energy efficient technologies. It reduced the relative disadvantage of new technology against conventional one in cost. In both cases studied here, the producers admitted the importance of investment subsidies in promoting their products, although it seems difficult to measure how much the subsidy really contributed to their sales.

The role of subsidy requires careful consideration. Although subsidy is an important instrument to support the initial deployment of new technologies, in the end these new technologies have to survive on the market without subsidy. In this sense, both the cases in this paper were "successful" only *so far*, which can be explained by the above mentioned factors, but may not be so *in the future*. Therefore, further research should investigate whether the two cases are really "successful" in surviving on their own in the future and what the enabling factors are.

Concluding discussions

The previous sections of this paper discussed the question "Is public R&D in energy efficiency really effective?" by examining the heat pump and waste heat utilization projects, which were the major projects in demand-side energy efficiency R&D in the 1980s and 1990s in Japan. The study focused on "commercialization" as a direct outcome from the projects to be investigated. Firstly the status of development was investigated to understand how many of the technologies have been commercialized. Secondly the development process of two commercialized technologies were analysed to explore key factors for successful commercialization and diffusion.

The fact that the majority of the technologies developed in the projects failed in commercialization clearly shows the high-risk nature of public R&D projects in energy efficiency. But at the same time, the result indicates the effectiveness of energy efficiency R&D projects, i.e. they can bring new energy efficiency technologies to the market at a certain probability of success. Although it is not possible to make any statistical discussion concerning the rate of commercialization from public R&D based on this one single case study, the rate of commercialization in this paper (seven out of 34) seems to be reasonable compared to other public R&D projects (e.g. NEDO, 2007).

This raises one interesting question: "Is the success probability of a public R&D program better the higher it is?" While the answer should be "yes" for private R&D, it is not necessarily so for public R&D. Since public R&D is supposed to compensate under-investment in the private R&D activities caused by market failures, it should be directed toward risky projects that the private does not dare to finance by themselves (Mowery, 1995; Jaffe et al., 2005). It is thus reasonable that public R&D has a low rate of success. As Scherer & Harhoff (2000) say, "*programs seeking to advance technology should not be judged negatively if they lead to numerous economic failures; rather, emphasis should be placed on the relatively few big successes.*"

The importance of continuous support for private R&D in energy efficiency was also confirmed in the two case studies of successful commercialization. In both cases, the NEDO projects and their follow-up projects (either by NEDO or by power companies) were indispensable for private companies to start and continue R&D investment into such risky but innovative technologies. Thus the results of this study indicate that long-term public R&D support toward risky technologies is an effective policy instrument to promote creation and diffusion of innovative energy efficient technologies. However, while public R&D should facilitate risky technologies, it should not be wasted. Choosing right technologies is therefore a very crucial step when designing public R&D programs. It is also inappropriate to continue funding for technologies which already turned out to be unpromising, thus the government needs to be careful when choosing technologies to support. This point is beyond the scope of this study but should be investigated in further research.

Finally, the existence of the Darwinian Sea, the challenge which innovative technologies faces before reaching wide deployment, also has an important implication. The case study of the high efficiency heat pump by Kobelco shows that overcoming the Darwinian Sea requires not only technical improvements but also marketing efforts, such as careful understanding of market characteristics, specification of favourable market segments, and improvement of the products already in demand by the market. This is a major subject of marketing science (e.g. Kotler & Gary, 2001), but is seldom stressed when discussing energy efficiency or energy technology policy. In order to increase innovative energy efficiency technologies on the market, the importance of marketing and ways to overcome the Darwinian Sea in technology development process seem to deserve more attention.

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Acknowledgements

The author kindly thanks the respondents at the studied companies for giving their time. The author would also like to thank Dr. Hiroyuki Kudo of Energy Conservation Center of Japan, Dr. Yoshiyuki Kozawa of Central Research Institute of Electric Power Industry (retired) and Peter Popovics of TUV Rheinland Japan for their generous cooperation.