Electricity Saving Potential and Cost & Benefit of LED Lighting in Japan

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Summary

In the wake of the Tohoku-Pacific Ocean Earthquake that badly affected Fukushima Daiichi Nuclear Power Plant, the nuclear power policy in Japan will inevitably be revised. Though fossil fuel power plants and renewable energy are drawing greater attention as alternative power sources, energy savings on the demand side should also be taken into consideration.

This paper estimates the electricity saving potential and also the cost and benefit of the introduction of LED lighting as an energy saving measure on the demand side. If all of the existing incandescent and fluorescent lamps were replaced by LED lamps, 92.2 TWh could be saved, a figure accounting for 9% of the entire electricity consumption in Japan. This amount equals the electricity produced by 13 nuclear power plants and 88 GW of photovoltaic power. The initial cost reaches up to 16 trillion JPY, but is still much less expensive than the 53 trillion JPY needed for photovoltaic installation to generate the same amount of electricity saved by LED lighting. In the case of replacement of incandescent bulbs by only LED bulbs, whose prices are rapidly decreasing, 27.3 TWh of electricity consumption can be saved (equivalent to four nuclear power plants and 26GW of photovoltaic power), and the cost of replacement is 850 billion JPY, which is less expensive than the case where the LNG thermal power plants generate the same amount of electricity (200 billion JPY/year).

Measures such as new and alternative power development require not only substantial amounts for investment but also the securing of land, understanding from the neighboring residents, and a long lead time. Meanwhile, electricity saving measures on the demand side are much less expensive and can be started quickly.

As the price of LED lighting is still expensive when compared with conventional lighting technology, the central government and local governments are providing a variety of support measures for promotion. Nevertheless, at present, LED lighting is mostly included as one of the components of the energy saving or renewable energy promotion package. Further promotion of LED lighting would require establishment of support measures putting focus strongly on LED lighting. For households sensitive to the initial cost, support measures such as discount at the point of purchase like “Eco-Point” would be effective. There are some areas in Europe and the United

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States where measures to distribute CFLs (Compact Fluorescent Lamps) free of charge to households are implemented. For the business sector, tax benefits or subsidies to alleviate the energy saving investment burden would be effective.

Introduction

The earthquake that occurred in the eastern part of Japan on March 11 damaged the energy supply system of Japan. The rolling blackouts and shortages of fuel have impressed people anew with the importance and indispensability of energy for economy and society. Such social disruption would be settled along with restoring the affected areas. The more serious problem is rather the perspectives on nuclear power plants. The earthquake and tsunami have badly damaged Fukushima Daiichi Nuclear Power Plant. The nuclear power plants are key measures in the energy and environment policy in Japan, as the “Energy master plan” places the nuclear power plants in the core energy supplying system that can simultaneously provide stable power supply, sustainability and economic efficiency (3E). The long term strategies of energy in Japan will inevitably be revised.

In the wake of the earthquake that caused serious damages to the nuclear power plants, the renewable energies represented by photovoltaic and wind turbine power are expected to replace nuclear power plants for power generation and are drawing greater attention than ever. Though the promotion of renewable energies is important, there still remain obstacles to be addressed, such as cost, intermittent supply, etc. Meanwhile, electricity saving on the demand side is also important. This paper emphasizes the importance of demand side energy savings such as LED (Light Emitting Diode) lamps. LED lamps are still expensive compared with incandescent lamps and fluorescent lamps, but have greater electricity saving potential. The cost and benefit of LED lighting is estimated and compared with the supply side measures.

1. Status quo of LED lighting

1-1 Features of LED Lighting

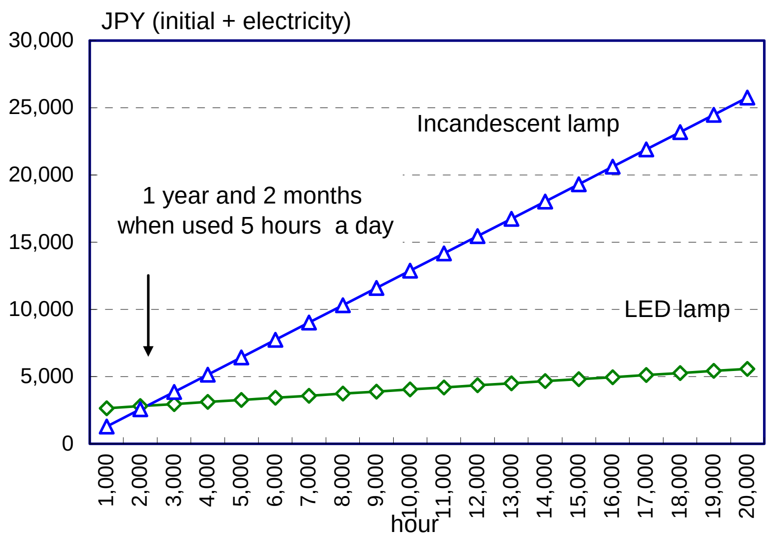
LED lighting is lighting apparatuses that use light emitting semiconductors and are drawing greater attention as fourth-generation lighting technology following the candle, incandescent lamp and fluorescent lamp. The red and lime-green LED was developed in the 1960s and was used principally for display. The development of the blue LED in 1993 and white LED in 1996 strongly pushed LEDs for lighting forward into practical use.

Table 1-1 Features of Lamps

	LED Lamp (bulb)	Compact Fluorescent Lamp (bulb)	Incandescent Lamp (bulb)
Power consumption (W)	7	12	54
Operating life (hour)	40,000	6,000	1,000
Retail price (JPY)	2,500	1,000	100

The most remarkable feature of LED lamps is that their operating life is 20 to 40 thousand hours, which is ten times longer than incandescent lamps and several times longer than fluorescent lamps. If an LED lamp is used ten hours a day, there is no need to replace it for ten years. Once installed, an LED lamp is almost maintenance-free and can save on replacement of components and fixings. In addition, with a large part of electricity input being used for light emission, the luminance efficiency (lumen/W) is eight times as high as for an incandescent lamp. However, the greatest disadvantage is that the price is high. Though the price has rapidly decreased since Sharp released the LED lamp (bulb) at a price half that of then-existing products, the cost of an LED lamp is still high, at 2,000-3,000 JPY, much more expensive than 100 JPY for an incandescent lamp or 1,000-1,500 JPY for a CFL (Compact Fluorescent Lamp). Nonetheless, since the operating cost can be largely reduced due to the long operating life and energy efficiency, reaching the breakeven point takes no more than a year when an incandescent lamp is replaced by an LED lamp (bulb) if the lamp is used five to ten hours a day.

Fig. 1-1 Comparison of cost in incandescent lamp and LED lamp



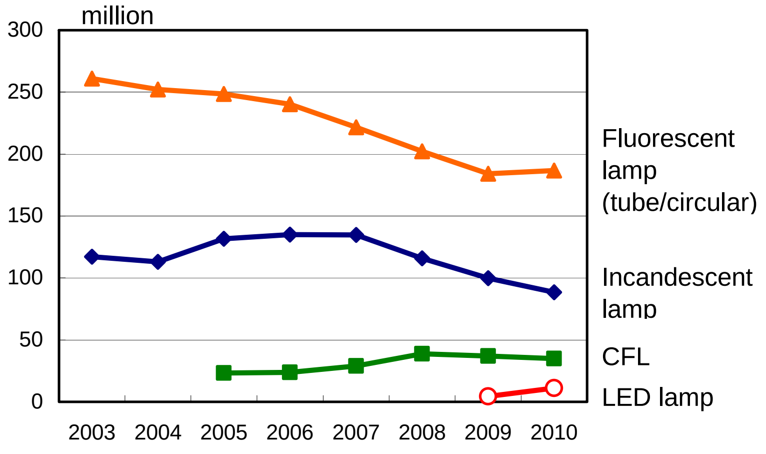
1-2 Market and Technology Trend of LED Lighting

The bulb LED lamp and tube LED lamp are currently commercialized. The bulb LED lamps were developed with a view to switching from incandescent bulb lamps and tube LED lamps are for tube fluorescent lamps. The bayonet caps should be compatible for replacement of lamps.

The bulb LED lamps with bayonet caps compatible with incandescent lamps (E26[1]) and miniature krypton lamp (E17) are on the market, and additional components and labor work are not required in most cases. On the other hand, though most tube LED lamps have bayonet caps compatible with tube fluorescent lamps (G13[2]), since they do not have the same starter system, there is risk of overheating and fuming if tube LED lamps which are not recommended are installed. The risk of falling of tubes heavier than the weight limit specified with a G13 bayonet cap (500g stipulated in JIS) is also pointed out. Addressing these issues, the standard (JEL801) concerning the starter system was established by the Japan Electric Lamp Manufacturers Association in October 2010 so that consumers can choose LED lamps easily and safely. It is indeed true that there are barriers against switching existing lamps to LED lamps like the requirement to replace fixings and additional labor work. However, a variety of lineups that corresponds to various lighting fixtures are expected to be launched to the market backed by technology development and establishment of standards.

Presently, diffusion of bulb LED lamps, having an advantage over tube LED lamps in easy switching, is proceeding. The price of a bulb LED lamp has remarkably decreased from 7,000-8,000 JPY two years ago to 2,000-3,000 JPY currently, and some bulbs are sold below 1,000 JPY. The domestic sales volume of bulb LED lamps, that was 4-5 million in 2009, is growing to 11 million in 2010. The market share of bulb LED lamps has reportedly reached 30%, exceeding CFL in April 2011, and then 40%, exceeding incandescent bulb in May.

Fig. 1-2 Sales volume of lamps



Source: "The Current Survey of Production," Ministry of Economy, Trade and Industry, Japan

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1 "E26" means a screw type bayonet cap with 26 mm diameter which is most commonly used in households.

2 This is the bayonet cap of the most common fluorescent tube. G5 is used for the thin type (4-8W). R17d is used for 110W, and RX17d for high frequency (Hf) fluorescent lamps.

One of the features of the LED lighting market is that quite a few emerging start-up companies are making a foray into the market. LED technology was originally developed in the semiconductor industry and many semiconductor manufacturers are making inroads into the LED market, seeing the market growth potential. Tens of manufacturers including large traditional lighting manufacturers are launching products and the market is getting very competitive. In addition, overseas firms from Taiwan, China and Korea are also entering into the Japanese market. Besides price competition due to this market intensity, technology innovation is also promoted in order to meet a variety of consumers needs, and LED lamps equipped with luminance- and color-adjustment functions were also commercialized. It is expected that the LED lamp market will grow further due to the high degree of competition and the technology innovation, and that the price will be, in parallel, reduced significantly by volume efficiency.

2. Estimation of Electricity Consumption for Lighting

The type of lighting depends on the places where it is used. Incandescent lamps create a relaxed and warm atmosphere and are frequently used in bedrooms, living rooms, and bathrooms and in hotels and restaurants as well. Fluorescent lamps create a sophisticated atmosphere through their strong brightness which is suitable for working, and they are used in offices and factories. HID (High Intensity Discharge) lamps (including mercury lamps and sodium lamps) have bright luminance and are used as street lamps and in sports facilities.

It is estimated that the total number of lamps currently used in Japan is 1.6 billion, of which there are 0.87 billion in the residential sector, 0.58 billion in the tertiary sector and 0.16 billion in the industrial sector. The largest number is 1.03 billion fluorescent lamps, followed by 0.34 billion incandescent lamps and 0.21 billion of CFL.

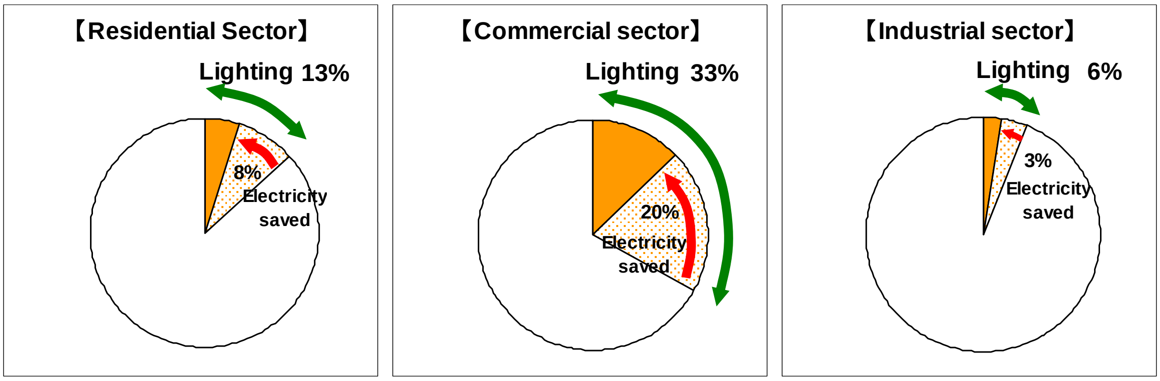
Table. 2-1 Number of lamps currently used

	Residential Sector	Tertiary Sector	Industrial Sector	Total
Fluorescent Lamp	0.46 billion	0.42 billion	0.15 billion	1.03 billion
Compact Fluorescent Lamp	0.15 billion	0.06 billion	-	0.21 billion
Incandescent Lamp	0.25 billion	0.08 billion	-	0.34 billion
High Intensity Discharge Lamp	-	0.01 billion	0.01 billion	0.02 billion
Total	0.87 billion	0.58 billion	0.16 billion	1.6 billion
Electricity Consumption	38.2TWh	89.1TWh	23.3TWh	150.6TWh

Note: As LED lighting has just begun to be used and consumes little electricity, the estimation excludes LED lighting.

The annual electricity consumption for lighting use is estimated to be 38.2 TWh in the residential sector, 89.1 TWh in the tertiary sector and 23.3 TWh in the industrial sector. The total is 150.6 TWh, accounting for 16% of the entire electricity consumption in Japan. Although the number of lamps in the residential sector is largest, the electricity consumption in the tertiary sector represents the largest percentage due to longer usage hours than the residential sector. Electricity consumption by fluorescent lamps represents 69%, CFLs 3%, incandescent lamps 21% and HID lamps 7%.

Fig. 2-1 Percentage of lighting electricity consumption by sector



3. Cost and Benefit of LED Lighting

3-1 Electricity Saving Potential of LED

The biggest disadvantage of LED has been its price being higher than conventional lighting technology. LED lighting has however started recently to diffuse as the price is getting cheaper. In order to figure out how much electricity will be saved by LED lighting, the electricity saving potential yielded by replacing all incandescent lamps, fluorescent lamps and HID lamps in Japan, except for CFL, will be estimated hereafter. It is assumed that incandescent lamps are to be replaced by bulb LED lamps, tube fluorescent lamps by tube LED lamps, circular fluorescent lamps by certain LED lighting and HID lamp by LED mega lamps[3]. The wattage of lighting is taken as the regular wattage.

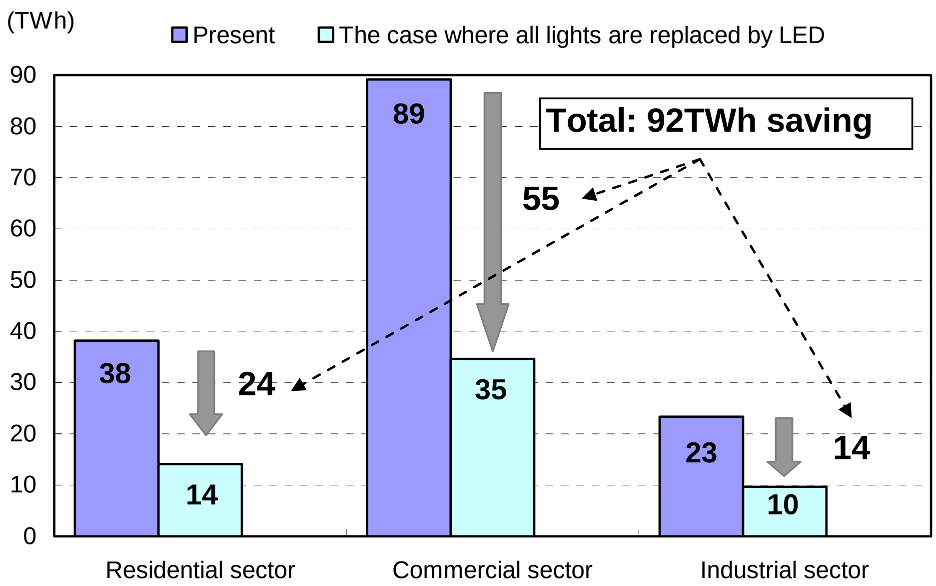
[3] At present, since circular LEDs have not been commercialized, it is impossible to replace circular fluorescent lamps. Replacement of fluorescent tubes by LED tubes often requires changes in fixings.

Table. 3-1 Wattage and price of lamps

before	Wattage	Price		after	Wattage	Price
Incandescent bulb	54W	100JPY	=>	Bulb LED	6-8W	2,000-3,000 JPY
Tube Fluorescent	45W	500 JPY	=>	Tube LED	20W	10,000-25,000 JPY*
Circular Fluorescent	35W	700 JPY	=>	LED lighting	18W	7,000-15,000 JPY
HID bulb	200W	6,000 JPY	=>	LED mega lighting	50W	100,000 JPY*

Note: *: Includes fixings and labor work cost.

Fig. 3-1 Electricity Saving Potential of LED



It is estimated that 92.2 TWh will be saved by replacement of all lighting by LED lighting[4], which accounts for 61% of the annual lighting electricity consumption and 9% of the entire electricity consumption in Japan. The breakdown is 24.1 TWh in the residential sector, 54.5 TWh in the tertiary sector and 13.6 TWh in the industrial sector.

The 92.2 TWh total saving equals the electricity generation of 13 nuclear power stations (1 million kW for each), 88 GW of Photovoltaic[5] power and 53 GW of Wind turbine power (the cumulative installation capacity of photovoltaic power and wind turbine power in 2009 is 2.63 GW

[4] Replacement of CFL by LED lamps is excluded, since electricity saving is limited.
[5] If all of the detached houses in Japan install photovoltaic power, the total power production capacity reaches 75 GW.

and 2.19 GW, respectively). 88 GW of PV and 53 GW of wind turbine power requires 880 km^2 (equivalent to 40% of Tokyo area) and 3,090 km^2 (equivalent to 1.4 times the Tokyo area), respectively. From the viewpoint of LNG thermal power stations, the electricity saving potential of LED lighting corresponds to 13.5 million tons of LNG (75.6 million tons imported in 2010).

3-2 Cost of replacement of all existing lamps by LED

Even though the cost of LED installation is expected to be reduced, if based on the current cost, the total initial cost incurred by replacement of all lighting by LED lighting is estimated to be 15.7 trillion JPY. The most costly is switching fluorescent lamps to LED lighting (13.1 trillion JPY), followed by HID (1.8 trillion JPY) and incandescent lamps (850 billon JPY). If the electricity saving by LED is supposed to be met by photovoltaic power generation and wind power, it would cost 53 trillion JPY and 13 trillion JPY[6], respectively. If LNG thermal power stations would supply this amount of electricity, 680 billion JPY of the LNG import cost would be added annually.

Table. 3-2 Initial costs of replacement of all existing lamps by LED lamps and cost of alternative power sources (92 TWh)

	Required amount	Initial Cost (trillion JPY)		Unit price (JPY/kWh)	CO_2 emission (million t-CO_2)
			Annual cost (for 10 years)		
Replacement by LED	1.4billion	15.7	1.6	17.0	-
Photovoltaic power	88GW	52.6	5.3	57.1	-
Wind power	53GW	12.6	1.3	13.7	-
LNG thermal power	13.5 million t-LNG/year	-	0.7	7.3	36
Nuclear power	13 plants (13GW)	-	-	-	-

Note: Photovoltaic includes only residential use and wind power includes only on-shore. The power system stabilization cost required with the mass introduction of renewable energies is not included.

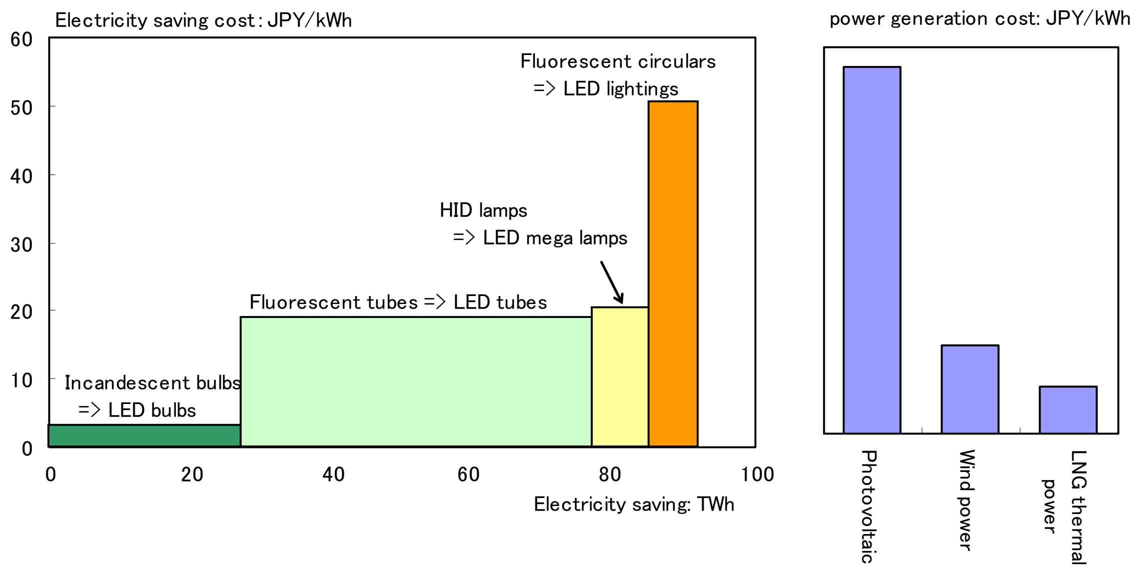
In general, the costs can be expressed per kWh so that the comparison among costs for each technology can be simplified. Assuming the usage period of LED as ten years, replacement by LED would cost 17.0JPY/kWh. If photovoltaic, wind power and LNG power generate electricity equal to the amount saved by LED, the photovoltaic would cost 57.1JPY/kWh, wind power 13.7JPY/kWh and LNG thermal power 7.3JPY/kWh. The cost of replacement by LED is much smaller than for photovoltaic but a little larger than for wind power. It should however be noted that

[6] Photovoltaic includes only residential use and wind power includes only on-shore. The power system stabilization cost required with mass introduction of renewable energies is not included.

the cost for a stable power system supposed to be incurred by the introduction of renewable energy mass is not included. The LNG thermal power station is least costly but emits 36 million t-CO2 annually (equivalent to 3% of 1990 emission).

The price of bulb LED lamps is dropping rapidly, presently 2,000-3,000JPY, and can be shortly paid back by replacing incandescent lamps with LED lamps[7]. Meanwhile, tube LED lamps are still expensive, 10,000 JPY including fixing and labor cost, and benefits can be hardly brought about when fluorescent lamps and HID lamps are replaced by LED lamps. As tube fluorescent lamps, which are the most widely possessed, has the largest electricity saving potential, cost reduction of tube LED lamps is strongly expected so that replacement could be encouraged.

Fig. 3-2 Electricity Saving Cost and Potential by LED Lighting



Then, more realistically, the electricity saving potential through replacement of only incandescent lamps by bulb LED lamps is calculated herein. The electricity saving potential is 27.3 TWh, accounting for 3% of the total electricity consumption in 2009 and equivalent to the electricity generation of four nuclear power plants (1 GW each). The total cost for replacement is 850 billion JPY and the electricity saving cost is estimated to be 3.1JPY/kWh, lower than the electricity generation cost of LNG thermal power plants.

7 The cost of electricity saving calculated by initial cost and running cost (subjective break even time is assumed to be 5 years) is -16.0JPY/kWh, which means negative cost.

Table. 3-3 Initial costs of replacement of all existing incandescent lamps by bulb LED lamps and cost of alternative power sources (27.3 TWh)

	Required amount	Initial Cost (trillion JPY)	Annual cost (for 10 years)	Unit price (JPY/kWh)	CO_2 emission (million t-CO_2)
Replacement by LED	0.3 billion	0.8	0.1	3.1	-
Photovoltaic power	26GW	15.6	1.6	57.1	-
Wind power	16GW	3.7	0.4	13.7	-
LNG thermal power	4million t-LNG/year	-	0.2	7.3	11
Nuclear power	4 plants (4GW)	-	-	-	-

Note: Photovoltaic includes only residential use and wind power includes only on-shore. The power system stabilization cost needed for mass introduction of renewable energies is not included.

The estimation revealed that the electricity saving potential by LED lamps is significantly large in Japan. If the electricity equivalent to this saving potential by LED lamps is met by the supply side, higher power production costs and security would be major challenges. On the other hand, LED introduction, in particular, replacement of incandescent lamps by bulb LED lamps, is easy to do right now and brings benefits as well.

4. LED Promotion Policies

The government of Japan announced a request for manufacturers to cease production of incandescent lamps by 2012. In accordance with the request, some of the major manufacturers have voluntarily started phasing out production of a part of incandescent lamps. It is highly likely that this trend will push forward the replacement of incandescent lamps by CFL or LED lamps, accelerated by the fact that bulb LED lamps have substantial economic benefits. However, the obstacles against wider diffusion of tube LED lamps persist in terms of replacement of fluorescent lamps, as it takes longer than 10 years to break even.

As the price of LED lighting is still expensive when compared with conventional lighting technology, the central government and local governments are providing a variety of support measures for promotion. Nevertheless, at present, LED lighting is mostly included as one of the components of the energy saving or renewable energy promotion package. Further promotion of LED lighting would require the establishment of support measures putting focus strongly on LED lighting. For households sensitive to the initial cost, support measures such as discount at the point of purchase like “Eco-Point” would be effective. There are some nations in Europe and the United States where measures to distribute CFLs free of charge to households are implemented. For the business sector, tax benefits or subsidies to alleviate the energy saving investment burden would be effective.

Table. 4-1 Costs of LED Lighting

	Unit price	Payback time
Incandescent bulb => Bulb LED	2,000-3,000JPY	1 year & 5 months
Tube Fluorescent => Tube LED	10,000-25,000 JPY*	9 years & 11 months
Circular fluorescent => LED lighting	7,000-15,000 JPY	18years & 6 months
HID lamp ⇒LED mega lighting	100,000 JPY*	10 years & 11 months

Note: * Includes fixing and labor works

Concluding Remarks

In the wake of the Tohoku-Pacific Ocean Earthquake, thermal power stations and renewable energies are very often at the center of discussion on replacement of nuclear power stations. However, it should be remembered that electricity saving on the demand side is also very important. This paper shows that electricity saving on the demand side represented by LED lighting has a good advantage in cost-benefit over a measure on the supply side (power development). The cost needed in replacing incandescent lamps by bulb LED lamps is significantly smaller than the cost carried by the case where the amount of electricity saved by LED bulbs is supplied by power plants. On the other hand, it was revealed that to promote replacement of fluorescent lamps by LED lighting, cost reduction in LED lighting including fixings and labor work and further energy efficiency improvement are big challenges.

In fact, it is true that it will take considerable time for all existing lamps to be replaced by LED lighting. Strengthening the support measures for the introduction of LED lighting by the central government and local governments is needed so that this time can be shortened. With such support, the LED lighting market will presumably grow rapidly, as the LED diffusion potential is large and many firms are active in the market. In addition, the cost is expected to be reduced due to volume efficiency.

The measures such as new and alternative power development require not only substantial amounts for investment but also the securing of land, understanding from the neighboring residents, and a long lead time. Meanwhile, electricity saving measures on the demand side are much less expensive and can be started quickly. LED lighting was shown in this paper as a good example, and the electricity saving potential in household appliances is also presumed to be great (See appendix). Energy saving has a quick effect and sustains its saving effect over time. As promoting energy saving provides benefits and advantages for the national economy, support measures for promoting energy saving are expected to be implemented further.

References

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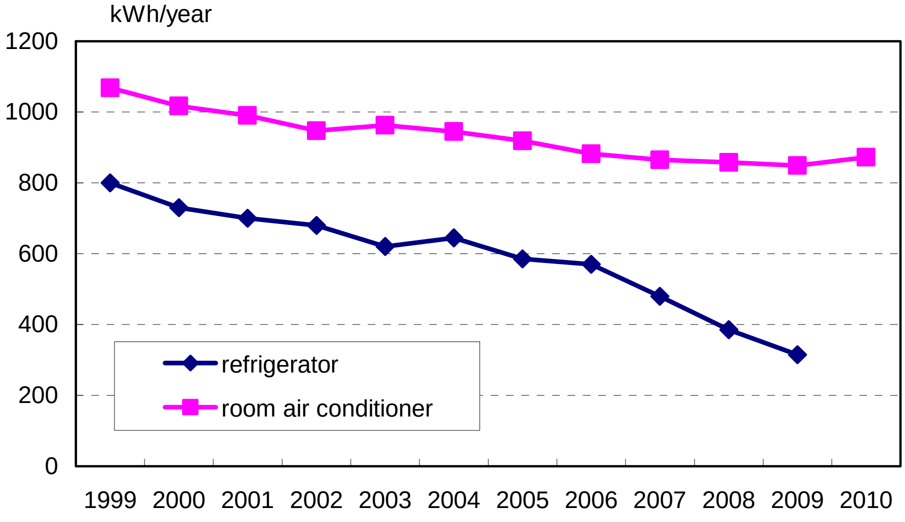
Homepages of manufacturers (*in Japanese*)

Appendix: Electricity Saving Potential in Household Appliances

Besides lighting, many appliances are used in households. In particular, room air conditioners and refrigerators consume large amounts of electricity. However, the energy efficiency of these appliances has been significantly improved since the implementation of the Top Runner scheme. Comparing the present products with those of 10 years ago, room air conditioners improved in energy efficiency by 20% and refrigerators by 60%.

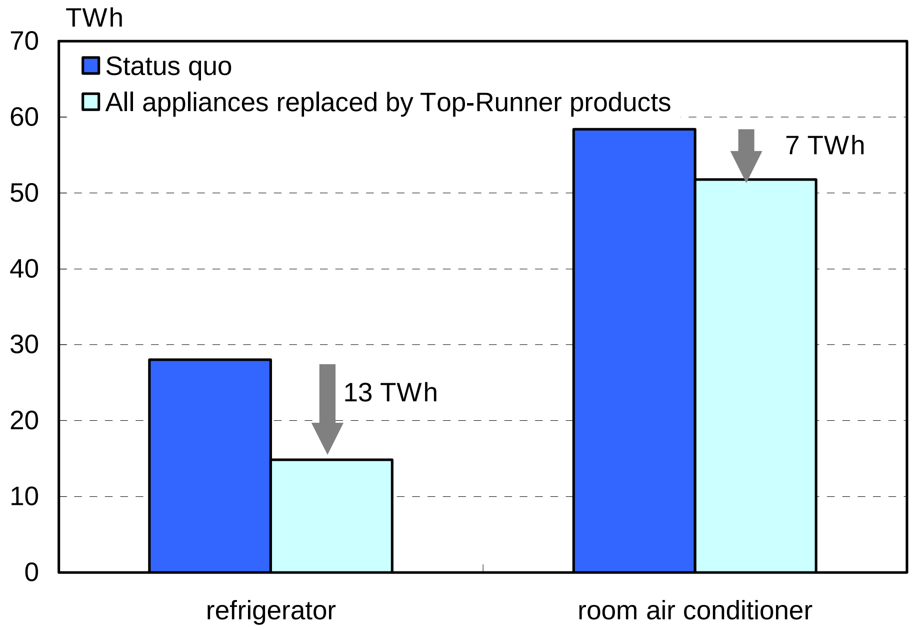
Fig. A-1 Annual electricity consumption of room air conditioners and refrigerators



Source: "Energy Efficiency Catalogue,, Ministry of Economy, Trade and Industry
Note: Room air conditioner is for 2.8kW of cooling capacity and refrigerator is for 401-450 L.

If all of the room air conditioners and refrigerators possessed in households were replaced by Top Runner products, the electricity saving potential is estimated to be 6.6 TWh in room air conditioners and 12.3 TWh in refrigerators, accounting for 2% and 5% of the total electricity consumption in the residential sector, respectively. The total electricity saving potential of the two appliances, 19.8 TWh, roughly equals the electricity saving potential in lighting in the residential sector (24.1 TWh). This is equivalent to 2% of the entire electricity consumption in Japan, corresponding to the electricity generation of three nuclear power plants and 19GW of photovoltaic power.

Fig. A-2 Electricity saving potential in room air conditioners and refrigerators



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