LBNL-43782
L-216

Presented at the 1998 ACEEE Summer Study on Energy Efficiency in Buildings, August 23-28, 1998, Pacific Grove, CA, and published in the Proceedings.

Creating Markets For New Products To Replace Incandescent Lamps: The International Experience

Francis Rubinstein
Building Technologies Department
Environmental Energy Technologies Division
Ernest Orlando Lawrence Berkeley National Laboratory
University of California
1 Cyclotron Road
Berkeley, CA 94720

Nils Borg,
Borg&Co
Sveavagen 98, 4tf
Stockholm S-113 50 SWEDEN

Noah Horowitz,
Natural Resources Defense Council
71 Stevenson Street, Suite 1825
San Francisco, CA 94105

Tracy Narel,
U.S. Environmental Protection Agency
401 M Street, SW, Mail Code 6202J
Washington, DC 20460

E. Thomas Morehouse Jr.
Institute for Defense Analyses
1801 North Beauregard Street
Alexandria, VA 22311-1772

March 1998

This work was supported in part by Borg & Co., Natural Resources Defense Council, the U.S. Environmental Protection Agency, and the Institute for Defense Analyses, through the Assistant Secretary for Energy Efficiency and Renewable Energy, Office of Building Technology, State and Community Programs, Office of Building Equipment of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.1

Creating Markets For New Products To Replace Incandescent Lamps:
The International Experience

Francis Rubinstein, Lawrence Berkeley National Laboratory
Nils Borg, Borg&Co
Noah Horowitz, Natural Resources Defense Council
Tracy Narel, U.S. Environmental Protection Agency
E. Thomas Morehouse Jr., Institute for Defense Analyses

Abstract

Since the summer of 1995, several organizations have been in pursuit of what many consider the "Holy Grail" of lighting technology—a low-cost, drop-in, energy-efficient replacement for the incandescent lamp. This paper summarizes the international experience in attempting to catalyze the commercialization of a mass-market replacement product that could have a major impact on residential lighting energy consumption in U.S. and EU homes.

The technology procurement effort was originally spearheaded by the U.S. Federal Government through a loose collaboration between the Department of Defense (DOD), the Environmental Protection Agency (EPA) and the Department of Energy (DOE). The DOD agreed to serve as the "anchor buyer" for a low-cost, drop-in replacement product for standard-sized light bulbs that provide at least 30% energy savings compared to traditional incandescent lamps. In parallel to the U.S. effort, the International Energy Agency launched a cooperative technology procurement effort by assembling large buyers' groups in Finland, the Netherlands, Sweden, and the United Kingdom to "pull" a similar efficient lighting product into the European market. The lukewarm response from lamp manufacturers to these two technology procurement efforts illustrates the challenges of transforming residential lighting from incandescent to efficient lighting.

Introduction

Few things better symbolize inventiveness and ingenuity than the incandescent light bulb. The popular incandescent bulb, one of the oldest technologies of the industrial age, is produced in prodigious volumes both in the EU and in the U.S. In 1993, the U.S. produced approximately 1.8 billion "large incandescent" lamps for domestic consumption (Vorsatz 1997) while the EU produced approximately 1.3 billion incandescent lamps for use in Europe (Kofod 1997). Other than incremental improvements in filament design and optical efficiency, incandescent lamps have changed significantly only twice since their invention in the last century: first in the 1960s, with the refinement of the tungsten halogen lamp, and then in the 1980s, with the development of halogen infrared reflecting lamp.

From an energy efficiency standpoint, the development of the halogen infrared reflecting (HIR) lamp in 1982 is the more significant of the two improvements since it nearly doubles the efficacy of the standard incandescent lamp[i]. The halogen infrared reflecting (HIR) quartz capsule technology is already used in some commercial lamps. For over five years, General Electric has been producing PAR-style reflector lamps[ii] and double-ended tubular quartz lamps utilizing the HIR technology. In 1988, a well-respected General Electric engineer wrote (McGowan 1988):

> The IRF [infrared reflecting film] development, which represents one of the largest one-time improvements in the history of incandescent lighting, has moved incandescent lamp efficacy into the discharge lamp range. The challenge now is to apply the technology to general lighting service lamps at a cost low enough to be utilized in the billions of existing incandescent sockets.

We wondered, if the technology to make an incandescent lamp more efficient already existed as a commercially-available PAR lamp, why couldn't the inner burner from one of these PAR lamps serve as a tangible "proof-of-concept" that a more efficient general service[iii] bulb was possible? The real question, though, was whether manufacturers could profitably incorporate the promising HIR technology into a high volume consumer product selling in the 100s of millions or even billions of units annually. And then, how to convince lamp manufacturers that there was a sufficiently large market for such a lamp so that they would build it.

In this paper, we begin with a discussion of the incandescent lamp and the technological improvements that it has undergone since its invention. We then describe the market for incandescent lighting in the U.S. and in the EU, focusing on residential usage of this source and describe the drawbacks of some of the replacements that have so far been proposed for incandescent light bulbs (e.g., the compact fluorescent lamp). Next we present the energy efficiency and environmental impacts of a widely used, more efficient, lamp and describe the efforts that are underway, both in the U.S. and in Europe, to "pull" this technology into the market. The discussion summarizes the common global experiences in pursuing this endeavor and the implications for future technology procurement efforts.

The A-Lamp

The incandescent light bulb would be the perfect light source if it were not so inefficient and short-lived. It is small, inexpensive, produces a color and quality of light that we find pleasing, but typically lasts only 1000 hours. A 100 watt incandescent lamp produces only 17 units of light (lumens) for every watt input. Thus its efficiency is only 17 lumens per watt (compared to a fluorescent lamp which produces 50-70 l/w).

The incandescent light bulb has slowly improved since Edison's time, both in terms of efficacy and lifetime. In Edison's day, these bulbs produced only 5 lumens per watt compared to today's 17 lumens per watt. But significant improvements were to come. For example, by surrounding an incandescent lamp filament with a small quartz capsule and adding a special gas, lamp engineers created the tungsten halogen lamp—the lamp used in halogen torchieres, which have become extremely popular recently in American homes. Despite the fact that halogen torchieres are marketed as "energy-efficient," the tungsten halogen lamp is only slightly more efficient than a regular incandescent lamp.

The HIR Concept

The halogen infrared reflecting lamp is a major advancement in incandescent lighting technology. By encapsulating the incandescing filament in a specially-formed quartz capsule onto which a multi-layer coating has been deposited, lamp engineers have created the HIR lamp which is much more efficient than a standard incandescent or tungsten halogen lamp. The multi-layer coating allows visible light to pass but wasted heat (infrared radiation) is reflected back onto the filament. This reflected heat warms the filament, thus reducing the need to supply electrical power and improving efficiency. The improvement in efficacy with this technology is impressive. For example, an HIR lamp, built to produce the same amount of light and with the same lifetime as a standard 60 watt incandescent lamp, would have an efficacy of about 26 l/w, compared to 15 l/w for the standard incandescent lamp (LBL 1995).

In 1995, LBNL reported the performance of a prototype general service HIR lamp produced by blowing an A-line style lamp envelope around a cannibalized 100-watt GE PAR-38 lamp. The measured efficacy of this prototype was about 26 l/w (compared to a 17 l/w standard 100 watt incandescent) confirming the supposition that existing technology could form the basis of an improved efficiency incandescent lamp.

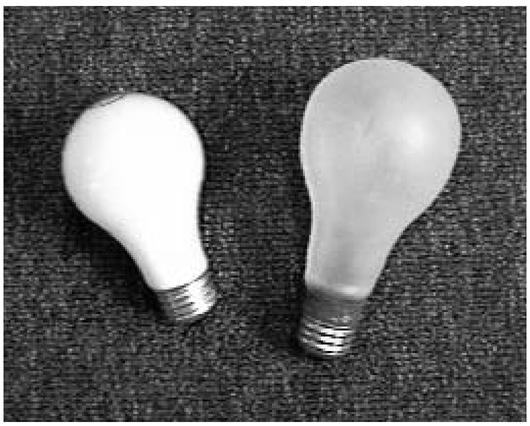

Figure 1. A standard 100 watt incandescent lamp (left) is shown next to a HIR lamp prototype (right) constructed at LBNL in 1995 (LBNL 1995). The standard lamp produces 1750 lumens at 100 watts input and has a 750 hour life. The prototype HIR lamp produces 2675 lumens at 100 watts with a 2,500 hour lamp life. Later prototypes (not shown) reduced the size of the HIR lamp's outer envelope to match the standard incandescent lamp's diameter.

The HIR lamp is a much more complex lamp than either a standard incandescent or tungsten halogen lamp. The manufacturing process required to deposit the multi-layer coating[iv] onto the HIR lamp capsule is technically difficult and manufacturers would need to develop techniques to make this deposition process more amenable to high volume production. (Currently, HIR capsules are produced primarily to serve the high-end PAR-lamp market, which is much smaller than the standard incandescent lamp market). Perhaps the most challenging part to producing a low-cost HIR lamp is the cost of producing the specially-formed quartz capsule. Unlike the tungsten halogen capsule, the HIR capsule must be carefully manufactured to exact optical specifications to be effective. Finally, designing a low-cost HIR lamp that can operate at European voltages (230 VAC) is more difficult than for the 120 VAC common in the U.S. This is because the filament for a 230 VAC lamp is much longer than a lamp filament of a 120 V lamp. Since the capsule that surrounds the 230 V lamp filament must also be longer, this increases the difficulty of producing a low-cost capsule. Furthermore, the longer filament may also migrate away from the optical center of the capsule during long-term operation, potentially reducing the light output (and efficacy) of the lamp towards end of life. The voltage difference between U.S. and EU tends to make the European HIR lamp a more difficult challenge than the U.S. lamp.

Market Characterization

A-lamps

Most general service A-lamps[v] are sold in the residential market although perhaps 20% of A-lamp sales are due to the C&I market. There are approximately 3 billion incandescent sockets in U.S. homes with annual sales of 1.8 billion general service lamps (1993). In the EU, sales were 1.35 billion units annually (Kofod 1996), which suggests an in-place inventory of 2.25 billion incandescent sockets in EU homes. Because a general service HIR lamp could fit in most incandescent sockets without equipment modification, the market potential in U.S. and EU homes is enormous.

The 60 watt incandescent lamp is, by far, the most popular wattage for incandescent lamps in the typical U.S. home (we assume that the distribution of wattages in EU homes is similar). As shown in Figure 2, the 60-watt incandescent lamp is the most common, followed by 100-watt and 75-watt lamps. Nearly two-thirds of all incandescent lamps in place are of these three wattages. Given the preponderance of 60- 75- and 100-watt lamps, strategies to replace the incandescent lamp must be able to provide comparable light output to the most popular wattages. In Figure 3, the distributions of household lighting sockets and energy consumption by hours of use are illustrated.

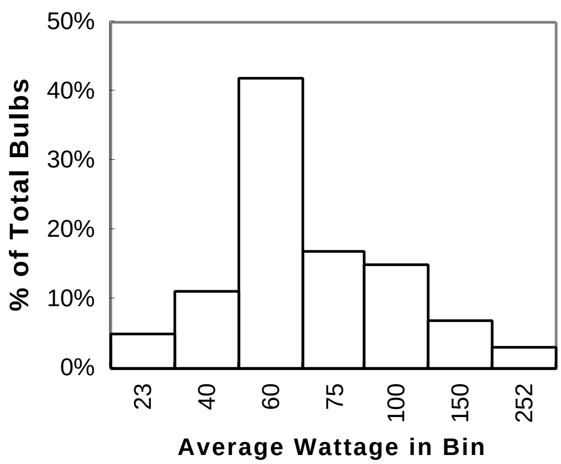

Figure 2. Distribution of incandescent lamps in typical U.S. home according to wattage.

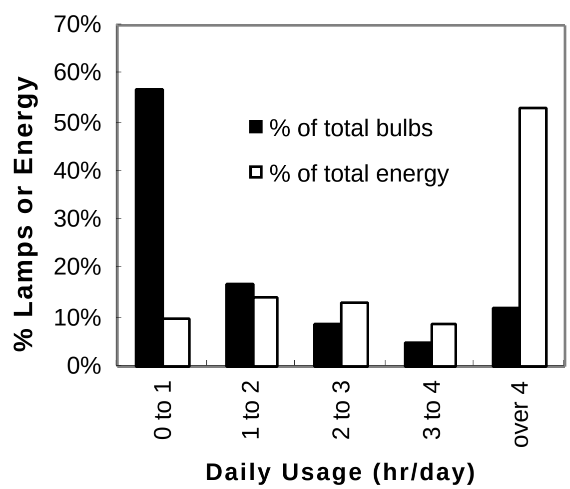

Figure 3. Percentage of sockets and percentage of total lighting energy usage broken down according to burning hours per day.

From these data, it appears that lighting energy usage in residences can be divided into two categories of fixture operation:

1. *Low-use* sockets (<3 hr/day) represent 70% of the sockets in the home and account for 33% of all household lighting energy.
2. *High-use* sockets (>3 hr/day) consume 67% of all lighting energy in household but represent only 30% of the total number of sockets.

These two usage patterns suggest that the residential lighting market should be viewed as two relatively distinct sub-markets, with a different strategy to reduce the energy consumption within each. However, it should be noted that the current crop of CFLs are not up to the challenge of filling all the high-use sockets because of technological flaws noted below. Demand side management efforts aimed at the residential lighting market have primarily focused on replacing existing incandescent lamps with screw-in compact fluorescent lamps. Existing studies indicate that penetration of CFLs into the residential market has been very low despite several years of demand side management programs. For example, (CEC 1997) estimates that CFLs consume only 1% of all residential state lighting energy. Penetration rates for CFLs in the EU are somewhat higher. Nonetheless, it is clear that the current crop of CFLs has not brought about any significant reduction in residential lighting energy consumption in the U.S. or the EU.

Compact Fluorescents

Compact fluorescent lamps (CFLs) can sometimes be used instead of incandescent lamps, and since they are far more efficient, CFLs can save money in some residential applications. But CFLs are bulkier and heavier than incandescents, and they don't always fit into existing fixtures. Most importantly, CFLs also much more expensive than incandescent lamps. Thus they aren't economical if the hours of operation are short (less than 2 hours per day). Our analysis shows that a super-efficient incandescent bulb would compete most effectively with CFLs in precisely those applications where CFLs are less appropriate and more costly than regular incandescents—in less-used, lower-wattage sockets.

The use of CFLs should be aggressively encouraged for those 30% of the sockets that are responsible for 70% of the energy use in a home. Of the remaining 70% of the sockets in a given household, CFLs will often not work, either because the fixture is on for too few hours a day to justify the expense of a CFL, or because the CFL will not fit for one of a variety of reasons. The four major reasons for not using CFLs are:

First cost too high. CFLs at their current costs would not be cost effective by the end-user's criteria either because the lamp replaced is of too low wattage or because the annual burning hours are too low. (Estimate 25% of sockets excluded).

The CFL will not physically fit in the existing fixture either due to interference with the ballast shroud on the fixture cover or because the lamp portion is too long for the existing fixture. (Estimate 50% of sockets excluded).

Applications where instant on is required. Although modern electronically-ballasted CFLs are faster to ignite than their earlier magnetically-ballasted cousins, most take up to one minute to reach 90% of brightness from when first energized and usually at least ten seconds before reaching 50% of full brightness. This has resulted in snap back or reversion to incandescent lamps in some residential applications where it has been tried. (Estimate 20% of sockets excluded).

An incandescent dimmer was previously installed. Most of these controls in the residential market have been designed around incandescent lamps (which are purely resistive loads) and will not work properly with CFLs. While there are various controls that will work with CFLs or other fluorescent products, they are not readily available in the residential market. (Estimate 10% of sockets excluded).

An "inexpensive" CFL (say $6-9/unit), while it might alleviate the first concern, would have no impact on the poor application fit in the other three category areas. Each one of these contraindications, taken separately, would only exclude CFLs from a relatively small percentage of residential sockets. Taken as a whole, they render at least 70% of the residential lighting socket inventory unavailable for CFL replacement[vi]. In fact, without Draconian measures such as legislation, it is unlikely that most of the remaining 27% of appropriate sockets will ever be filled with CFLs.

The target market for the HIR product should primarily be medium and low-use sockets as indicated in the analysis below. High use sockets should be the focus of a complimentary effort to accelerate the introduction of dedicated CFL fixtures as it is in a nation's long-term interest to promote the adoption of luminaires that use efficient sources (such as the pin-based CFL) for fixtures with long burning hours (> 3 hours/day). Efforts to encourage this sub-market should not be discouraged by an HIR procurement. These are two largely separate sub-markets and appropriate low-cost efficient products should be encouraged for both. In the long run, more efficient, better performing fixtures (such as dedicated CFL fixtures) should largely supplant almost all incandescent lighting in homes.

Benefits and Cost Analysis

Energy and Environmental Impacts

Because a general service HIR lamp could fit wherever an incandescent lamp is currently used, the market for the HIR lamp in U.S. and EU homes is enormous. There are approximately 3 billion incandescent sockets in U.S. homes today and the energy used for residential lighting accounts for about 137 BkWh/year ($11 billion/yr)—slightly over 25% of the nation's total energy budget for lighting. The inventory of incandescent lamp sockets in EU homes (2.25 billion sockets) is slightly lower than that of the U.S. which suggests that the total residential lighting usage in the EU is also lower (about 103 TWh/yr assuming similar usage patterns as the U.S.).

To calculate the national impacts of a widely adopted, inexpensive HIR lamp, we assume a scenario where HIR lamps replace all those incandescent lamps responsible for 1/3 of the total national (or, in the case of the EU, multi-national) residential lighting energy usage[vii]. Since the HIR lamp would reduce the energy usage by about 30% in every socket where adopted, the energy savings from this aggressive dissemination would be about 10% of total usage. This would result in energy savings of 13.5 and 10 TWh/yr for the U.S. and EU, respectively, and a total energy cost reduction to residential users of about $2 billion/yr.

The environmental consequences of widely used HIR lamps are likewise immense. Using typical conversion factors[viii] for relating avoided kWh to avoided CO_2 emissions, we find that a 23.5 TWh/yr reduction in primary energy usage in the U.S. and the EU (as calculated in the above scenario) translates into a reduction of 16 million metric tons (MMT) of carbon dioxide. Thus an aggressively used HIR lamp could help the U.S. and the EU make significant progress to meeting greenhouse gas emission targets agreed to by international conventions.

Cost Analysis

It is difficult to gain national support for an improved efficiency incandescent lamp unless the price of the proposed lamp is low enough that it can be justified in terms of the resultant energy cost savings when used for typical residential operating hours. These economic constraints provide a framework for determining the highest cost that purchasers should be willing to pay for a lamp in order for it to be considered cost-effective. In the case of the U.S. procurement effort, the purchase price of the HIR lamp had to result in a two-year simple payback for 1000 hr/yr operation. Alternatively, a life-cycle cost criteria could be adopted (such as was followed in the EU procurement effort). In this section, we present a life cycle economic analysis that demonstrates that for typical residential usage, an HIR lamp should cost no more than $4 (end-user price) in order to be considered a cost-effective alternative to the standard incandescent lamp.

As our starting point, we compare three lamps of similar lumen output: a 60-watt standard incandescent, a 43-watt HIR lamp and a compact fluorescent lamp. The values assumed for these lamp types in the economic analysis are as shown:

Table 1. Properties of Three Light Sources for Residential Applications

Lamp parameter	Unit	Incandescent	HIR	Compact Fluorescent
Unit cost	U.S.$/lamp	0.75	3.5	15
Power	watts	60	43	15
Lamp life	hr/lamp	1000	3000	6000

We perform a life cycle cost analysis on these lamps assuming that the time horizon for the analysis is 10 years, the annual discount rate is 10% and the cost of electric energy is $0.10/kWh. Using the life cycle cost equations from (Clear 1996), we present the net present value for the lamp cost and energy costs over the time horizon for each of the above lamp types in Figure 4 below. Several trends are seen in Figure 4. For 1 burning hr/day (upper left plot), the total present value of the standard incandescent and HIR lamps are roughly equivalent, while the CFL cost is higher. At 2 hr/day (upper right plot), the HIR lamp has the lowest total life cycle cost of all three lamps, while at 3 hr/day or more (lower left and right plots), the CFL has the lowest life cycle cost. This indicates that if an HIR lamp can be offered for $3-4/lamp (in this analysis we used $3.50/lamp), it would be more life-cycle cost-effective than either a standard incandescent lamp or CFL for shorter burning hours (< 3 hr/day), while at longer burning hours, the CFL would be the best economic choice.

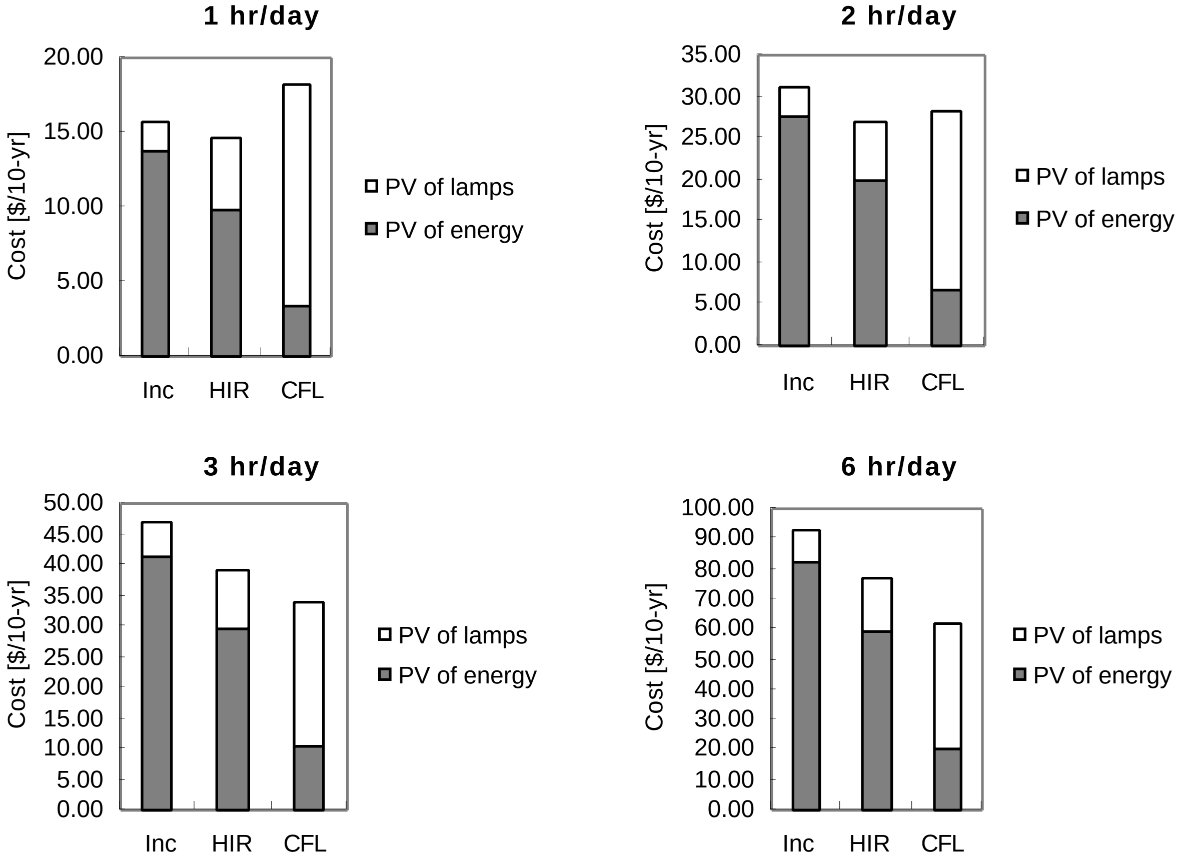

Figure 4. Present value of lamps and energy costs over the 10-year time horizon for a standard incandescent, HIR lamp and CFL for different assumed daily hours of operation.

Technology Procurement

Given the above considerations, technology procurement seemed the best way to convince manufacturers that there was a solid enough market for them to build an improved efficiency incandescent lamp. The essence of technology procurement is to bridge the gap between manufacturers who are unwilling or unable to develop improved products because they don't believe a market exists and those buyers who would like to purchase improved products but are unable to find them.

Technology procurement efforts to encourage the introduction of low-cost, drop-in replacements for the incandescent lamp have evolved along different paths in the U.S. and in the EU. In the U.S., the technology procurement stemmed from the potential buying power of a single large government agency (the Department of Defense). In the EU, the IEA acted as a neutral agency to initiate the process and orchestrate the assembly of potential buyers groups (primarily private) who were interested in purchasing large numbers of more efficient lamps.

U.S. Experience

The DOD issued a request for technical proposals (RFTP) to entice manufacturers to provide efficient, cost effective, A-line general service lamps that would fit in any fixture in which A-line incandescent lamps currently operate. The method of requesting bids was unusual in that it used a two step approach. In Step One, offerors submitted their technical proposals only. This included a detailed technical description of the product or products they proposed to meet the performance specifications. Step One consisted of the request for, submission, evaluation, and if necessary, discussion, of a technical proposal, to determine the acceptability of the products offered, but no pricing information was requested. Step Two was a sealed bid that was restricted to those offerors who submitted acceptable technical proposals under Step One.

The offerors were required to submit prototypes of the lamps offered within 6 months of the closing date of the RFTP. In order to consider all technologies that might satisfy the performance specifications, DOD encouraged offerors to submit multiple technical proposals presenting different basic approaches. Each submittal was evaluated separately, and without prejudice against any other offer submitted by a company.

The RFTP also required development, production, testing, and the supply of the first year's quantity of lamps within 3 years of the award of the contract. The total quantity requested was 6.6 million lamps over a 3-year period, with 2.2 million provided in the first year of delivery. The maximum lamp price the government was willing to pay was based on the performance of the lamp, with the basic criteria that the lamp must provide a 2 year simple average payback DOD-wide. The formulas used to calculate both the payback and lifecycle costs are available from the DOD, and include factors which reflect the average costs the DOD pays for electricity, including ratchet and other demand charges.

The following steps were taken by the Defense Supply Center - Richmond (DSCR) within DOD to initiate the technology procurement:

- Pre-proposal conference. Held in Richmond, Virginia (September, 1995)
- Solicitation of industry views and questions (September, 1995)
- DSCR response to industry inquiries and RFTP revisions (October, 1995 to May, 1996)
- Revised RFTP issued (May, 1996,
- DSCR received proposals (July 30, 1996)
- Evaluation of proposals (July to November, 1996)
- DSCR communicated that an amendment would be issued in the future to incorporate revisions to the statement of work and establish a new closing date for proposals (November 1996).

Since November 1996, DSCR has maintained on-going communications with its technical advisors and monitored the progress of the EU effort (see below). However, no additional steps have been take to advance the procurement. DSCR remains interested in the project but is simply waiting to see how complementary efforts develop.

EU Experience

In the EU, the International Energy Agency acted as a neutral agency to initiate the technology procurement and to assemble large potential buyers groups interested in the bulk purchase of a more efficient incandescent lamp replacement. In this case, the procurement proceeded according to (Davidson 1997):

1. Assemble groups of potential buyers in each country
2. Draft a product specification based on best knowledge of industry capabilities
3. Refine specifications and obtain potential buyer agreement
4. Issue final specification (request for proposal)
5. Assess returned manufacturer bids, modify specifications and re-issue if necessary
6. Theoretical assessment of tenders and selection of manufacturers for prototype testing
7. Prototype testing
8. Award contract for production of specified units at specified price and time period
9. Use prototypes for market conditioning activities (labeling, informational promotions, etc.)

The European competition was launched at the Hanover Light Fair in Germany on April 16, 1997. The call for tenders were presented at a seminar where representatives from all five major lamp manufacturers of the world were present: GE, Osram/Sylvania, Matsushita (Panasonic), Philips, and SLI. Moreover, the call for tenders was mailed to about 100 decision makers in the lighting industry in Europe, Asia and North America.

Manufacturers were given a month to ask questions and answers to these were sent out a month later. Tenders were due by the end of September 1997—three months after the last clarifications were sent out. However, no tenders that fulfilled the specifications were received, and the steering group had to decide if the competition should be called off or if the call for tenders should be reissued with modifications. Two months later, the group made a statement in which it said that the competition would be reissued, but in response to industry concerns, manufacturers would be given longer to respond to the reissued solicitation. In December 1997, the competition was reissued. As of this writing, the following key dates apply to the European Competition:

- Reissue of invitations to tender (December 1997)
- Competition entries due in to Building Research Establishment (BRE) by December 15, 1998
- Selected manufacturers invited to submit prototypes by March 16, 1999
- Prototypes due for testing by June 15, 1999
- Announcement of winner(s) in December, 1999
- First delivery to buyers in December 2000

Lessons Learned for Other Technology Procurement Programs

With the benefit of hindsight, we can speculate about how things might have turned out otherwise if a different technology procurement path had been taken. In retrospect, we believe the following should have been more fully considered:

A diverse buyers' group may be essential for this type of technology procurement to succeed. Although the U.S. DOD is probably the largest single customer in the world for this type of residential lighting product, having only a single customer leaves the industry skeptical of the product's viability beyond that one large buyer. A diverse buyers' group such as that assembled in the EU is a better indicator of broad residential market appeal than a single large customer. In the end, the carrot of a large initial purchase may not be sufficient to stimulate industry commercialization of a new product if there is not a firm belief that a sustainable market will exist after the market “pull” activities have ended. While an institutional, mass purchase can be a powerful first step in the commercialization strategy for a residential lighting product, the overall strategy must demonstrate the viability of the product in the residential sector.

The procurement should be structured to allow for variations in price as a function of final purchase volume. Such a structure would recognize that costs are higher for lower sales volumes. Including a schedule of prices and quantities would allow the purchaser to include a first-cost objective (i.e., the maximum price that they are willing to pay), while recognizing that lower volumes bring inherently higher prices.

It is important to begin an informal dialogue with industry prior to initiating a formal procurement for this type of consumer product. While there are ways for industry to have a dialogue within the formal Federal Acquisition Regulations, the formal process does not facilitate this.

Conclusion

The technology procurement efforts that have evolved in the U.S. and the EU indicates keen international interest in a low-cost, efficient, drop-in replacement for the incandescent lamp. Should such a product emerge, it could fill an important niche in the lighting market with major ramifications for residential lighting energy use. The lack of earnest manufacturer response to these solicitations illustrates the challenges of catalyzing new markets for energy efficient lighting products in a residential lighting market that is entirely dominated by first costs. The carrot of a large initial purchase of even millions of units may not be sufficient to stimulate industry commercialization of a new residential lighting product if there is not a firm belief that a sustainable market will exist for the new product after the market “pull” activities are ended.

Nonetheless, even if these efforts do not result in a new lamp as intended, several major lamp companies have accelerated their efforts to develop low-cost HIR technology partly as a result of this technology procurement effort. These efforts will result in new efficient lighting products even if the larger technology procurement should falter.

The final chapter of this story has not been written. Either we have helped to create a multi-billion dollar market for a better bulb to replace the ubiquitous incandescent lamp or we have dangled a golden carrot in front of the lamp manufacturers only to have nobody come to the auction. Only time will tell.

References

California Energy Commission, *Lighting Efficiency Technology Report: Volume 1 California Baseline*, May 1997.

Clear, R. and F. Rubinstein, “Evaluating the Relative Efficacy of Incandescent Lamp Technologies”, *Proceedings of the* 1996 *Annual Illuminating Engineering Society of North America*, Cleveland, August 1996.

Davidson, P. and N. Borg, "Building Buyer Strength for a Future Bulb: Developing a Functional Specification and Creating a Market for a Replacement Incandescent Lamp," *Proceedings of the Right Light 4 Conference*, Copenhagen, Nov. 1997.

Jennings, J., "Residential Lighting: The Data to Date", *Journal of the Illuminating Engineering Society of North America*, Summer 1997.

Kofod, C., L. Naser, and A. Rahbar, *Market Research on the Use of Energy Saving Lamps in the Domestic Sector*, Report DEFU TR-366, Research Association of Danish Electric Utilities, Denmark, June 1996.

Lawrence Berkeley Laboratory, *Building Technologies Program 1994 Annual Report*, LBL-36553, April 1995.

McGowan T, *Energy-Efficient Lighting*, Reprinted from *Electricity: Efficient End-Use and New Generation* Technologies *and Their Planning Implications*, Lund University Press, Lund, Sweden, 1988.

Vorsatz, D., L Shown, J. Koomey, M. Moezzi, A. Denver, and B. Atkinson, *Lighting Market Sourcebook for the U.S.*, LBNL Report LBNL-39102, December 1997.

Endnotes

[i] The efficiency of a light source (ordinarily expressed as lumens/watt) is correctly referred to as efficacy. Efficacy has units while efficiency does not.

[ii] PAR lamps are heavy glass reflectorized lamps that are commonly used for outdoor residential lighting.

[iii] The U.S. Census Bureau defines "general service" lamp as all large incandescent lamps used for general lighting purposes, 15 watts and above, 100-130 volts (including tinted lamps). In the EU, the term "general lighting service" (GLS) lamp appears to mean the same the U.S. "general service" lamps but at European voltages.

[iv] The multi-layer coating that GE uses in its PAR-type lamps consists of 40 alternating layers of tantala and silica that are deposited onto the outside of the formed quartz capsule.

[v] A-line lamps (or A-lamp for short) is the name given to incandescent lamps with the familiar "pear" shape. The diameter of a lamp (in the U.S.) is given in eighths of an inch. For example, the common 100 watt and 60 watt A-line lamp has an A-19 envelope (19/8 of an inch). The expression "A-line" is not used in the EU.

[vi] Assuming that the above factors are *independent*, the percentage of sockets not excluded for CFL replacement due to *any* of the factors is: 50% x 80% x 90% x 75% = 27% sockets not excluded for CFL replacement.

[vii] Even in this aggressive scenario, a significant fraction of total residential lighting energy would not be affected by the HIR lamp either because the socket burning hours are too short to justify even the cost of an HIR lamp, or because the burning hours are sufficiently long that a CFL would make a better economic choice for the consumer.

[viii] We assume 185 grams of carbon (or 679 grams of CO_2) are avoided for each kWh of primary energy avoided.