Fighting for Lighting and Cooking

Competing Energy Systems in Sweden, 1880–1960

Arne Kaijser

Introduction

The nineteenth century saw the successive introduction of three energy systems: gas, oil, and electricity. These were all high-value energy carriers that could be used for purposes from lighting to domestic heating. Their first applications were within the field of lighting, simply because this was the application that offered the greatest potential for charging the most for each kilowatt-hour. These energy systems then subsequently found their way to other energy markets—mechanical power, process heating, cooking, and space heating—where prices and quality requirements were lower.[1]

The introduction of new, high-value energy carriers into an energy market has generally given rise to a phase of intensive competition between traditional and new energy systems. In this chapter I will focus on two such competitions in Sweden: for the lighting and cooking markets. I will argue that the competitiveness of an energy system is dependent on one or several of the following means of competition ("the four p's"): *technical performance*, *pricing*, *propaganda*, and *political pressure*. In addition, I will discuss the fundamental difference between two kinds of energy systems: grid-based and non-grid-based systems.

I use the term *energy system* to signify a sociotechnical system, consisting not only of technical components but also of the people and organizations that build, operate, and use these plants, as well as the legal and economic framework of the system.

The purpose of an energy system is to provide a link between a raw material and particular energy needs. This link requires various forms of processing or conversion, as well as transportation. In terms of transportation requirements, energy systems can be divided into two main types:

- Grid-based energy systems (e.g., electricity, gas, district heating), in which final transportation to users is by means of a special physical network constructed solely for this purpose.
- Non-grid-based systems (e.g., oil products, coal, biomass fuels), where the final transportation to users is through existing transport systems.

These two types of energy systems differ in a number of respects. First, they differ in their *initial conditions*. A grid system requires a major initial investment before it can be put into operation: specifically, each new user must be connected to it by a separate pipe or wire. In contrast, a non-grid system can be built gradually, using existing roads, railways, and harbors.

The second difference relates to the *dependency factor*. A grid system creates a strong interdependency of suppliers and users. Users that employ the system for vital purposes depend on a supply without major interruptions, while suppliers depend on their users staying with the system, since the physical network cannot be moved or used for other purposes. A non-grid system is considerably more flexible, and thus the mutual interdependence of suppliers and users is weaker.

Third, the *operating conditions* differ. A grid system should attempt to achieve a reasonably high load factor, both for economic and technical reasons. Usually, the final users lack storage facilities, which means that grid systems must meet high-reliability requirements, since the rate of production must closely follow the rate of consumption. Each customer of a non-grid system, on the other hand, has its own buffer store, which helps to make the system more robust and insensitive to external disturbances.

The final difference lies in the *degree of public involvement*. A grid system is part of the physical infrastructure of a society. The pipelines or wires must be run above or below privately owned or publicly owned ground, requiring special permission or concessions from the state or community. Further, the monopoly position generally enjoyed by such a system requires society to apply some measure of control to ensure that the monopoly is not misused.[2]

The Struggle for the Lighting Market

Until the mid-1800s, a fire in an open fireplace was the main source of light for most Swedish households, both in urban and in rural areas. The middle of the century saw the establishment of factories producing tallow and stearin candles, which met a rapidly growing demand. Gasworks were also established in larger and medium-sized towns, to supply gas for street lighting and for lighting in workplaces and the homes of the wealthy. Sweden had no coal deposits; therefore, gas production depended on coal imports.[1]

At the end of the 1860s, the kerosene lamp appeared as a new competitor on the lighting market. The development of oil drilling technology allowed kerosene to be supplied at quite a low cost compared to gas. Kerosene lamps were also simple and relatively inexpensive, and required no pipes. Compared to grid-based gas lighting, available only in major towns with gasworks, kerosene lighting spread very quickly, even to remote villages in the countryside.

At the beginning of the 1880s, a further competitor appeared on the scene: the incandescent electric lamp. Even at that early stage, it offered several important technical advantages. It was described as follows, in a lecture given in 1883 to the Swedish Engineers' Association:

> The light produced is delightful, burning steadily without the least flickering or change, and having the warm, comfortable colour to which we are accustomed from earlier times. It releases little heat and no products of combustion. All the lamps in a circuit light instantly without having to be touched, and can be surrounded by the most flammable of items without risk of conflagration. With these lamps, it is possible to provide lighting equivalent to 6, 12, 16 or even up to 20 standard candles. In a word, they possess most of the attributes that can be required of an artificial light.[3]

The author of this somewhat lyrical description was not any representative of the Edison Company, as the reader might suspect. On the contrary, it was one of the senior members of the Swedish gas industry, the chief engineer of the Stockholm gasworks, Adolf Ahlsell.

Ahlsell praised all the purely technical characteristics of the incandescent lamp, but was also careful to point out that its costs were so high that "the electric light (will not) in any way replace gas lighting. . . . It is likely to find its first more general application as luxury lighting, where cost is of no consideration."[3]

Around the turn of the century an intense struggle for the lighting market developed not only in Sweden but also internationally. Lighting was the first major market for oil, gas, and electricity, and so the outcome of this struggle was of considerable importance for the continued development of these energy systems.

Performance and political pressure became important means of competition in this battle.

Performance

The major cost element of all three types of lighting was that of energy itself, and so their efficiency (i.e., the amount of light produced in relation to the amount of energy used) was a factor of vital importance. During the decades around the turn of the century, international technical development in the lighting area was impressive.

The first major advance was made within the field of gas lighting, with the introduction of the incandescent mantle. In traditional gas lamps, the burning gas itself constituted the source of light, while in the incandescent gas lamp, the burning gases heated a mantle with special metal oxides. It was this mantle that created the light. The efficiency of the new lamps was eight times higher than that of traditional gas lamps. However, the light was perhaps not as aesthetically attractive; not, at any rate, if we are to believe this description by the Swedish novelist Hjalmar Söderberg in 1907:

> It is still dark. A single gas flame flickers lazily through the frosty haze, and I trudge to school. Oh, I still remember the reddish-orange gas lamps of my childhood: how warmly and welcomingly they shone over the snow! Then came the deathly green Auer light.[4]

The incandescent gas mantle achieved rapid acceptance during the 1890s, and contributed greatly to augmenting the competitiveness of gas lighting, making it even cheaper than kerosene lighting. This development fostered great optimism in the gas industry, as is illustrated by Figure 1.

The development of the incandescent mantle exemplifies a general tendency pointed out by the economic historian Nathan Rosenberg: an established technology threatened by a new technology often undergoes considerable improvement in a last effort to survive. This is often forgotten later when the new technology has pushed the old technology out of the market.[5,6]

The manufacturers of electric lamps also tried to improve efficiency. By the end of the 1800s, they had succeeded in developing a new type of carbon filament with a light output that was twice as high as that of the first carbon filaments. The major advance occurred, however, when manufacturers succeeded in producing metal-filament lamps shortly after the turn of the century. In 1910, a tungsten-filament lamp was three times as efficient as the best carbon-filament lamp, with a corresponding cost reduction, as shown in Figure 2. The new lamps were quickly accepted during the 1910s.[7]

The most spectacular technical development during the struggle for the lighting market therefore occurred with the lamps themselves: the efficiency of both gas and electric lighting increased by nearly ten times over a period of 30 years! However, important advances in production and distribution also occurred.

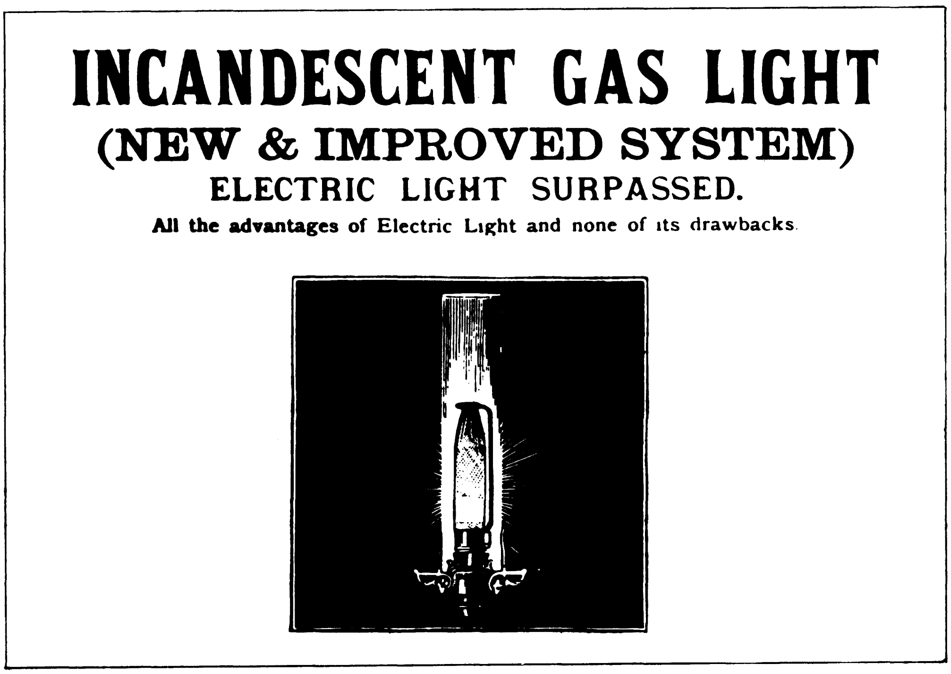

Figure 1. Advertisement in *Journal of Gas Lighting*, December 1890.

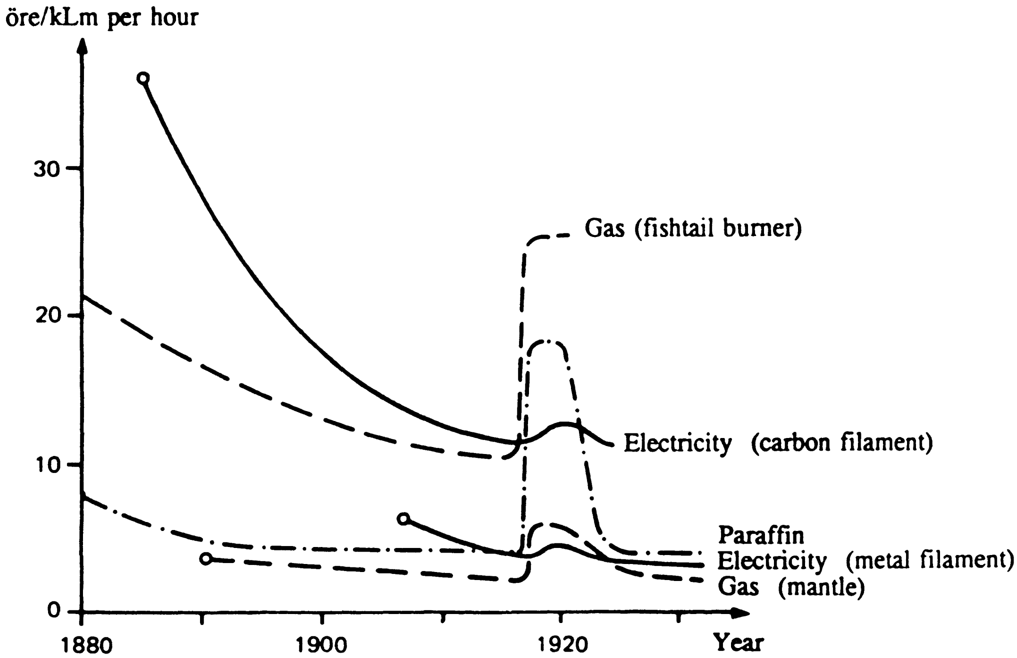

Figure 2. Cost per unit of light for different types of lighting in Sweden, 1880–1930.

In the gas industry, considerable improvement took place in the performance of ovens through application of the regenerative principle, thus reducing their tendency to leak gas and increasing their size. As a result, overall efficiency of gas production (gas and coke production versus coal consumption) rose from 30 percent to 65 percent during the last decades of the nineteenth century. Further, the necessary labor force was reduced to about one-tenth. These advances allowed the price of gas in many towns to be halved between 1880 and the end of the century.[1]

In the electricity industry the most important development was in transmission. During the 1890s, alternating-current (ac) technology was developed, which made it possible to exploit waterfalls located at great distances from towns and industry. The proportion of hydropower in Sweden's electricity production increased from 18 percent in 1885 to 60 percent at the turn of the century, with resulting significant reductions in production costs.[8]

Political Pressure

In technical and economic terms, gas lighting was more or less comparable with electric lighting until the introduction of the metal-filament lamp. Until then, the poorer quality of gas lighting was made up for by its lower price. This equilibrium meant that institutional conditions played an important part in the struggle between the two systems.

At the end of the century, gas lighting was backed by powerful and influential interests. Almost all the largest towns in Sweden had gasworks that were owned and operated either by the town council or by a private company mostly owned by the town's wealthier citizens. In many towns with gasworks, the decision to build a power station was therefore preceded by a long, hard struggle. The town of Linköping is a typical example.

Linköping had a publicly owned gasworks built in 1861. The battle started in 1886, when the board of the gasworks applied to the town council for permission to rebuild the gasworks. However, the council decided first to investigate the feasibility of switching to electric lighting. Since the director of the gasworks was a powerful advocate of the scheme to enlarge the gasworks, while three council members had recently purchased a number of waterfalls close to the town, this decision triggered a battle that lasted for 10 years. The struggle surged back and forth, and dominated the political debate in the town.

In the end, the proposal of the gasworks board to build a new gasworks and to shelve the plans for an electrical power station was accepted in 1896. Then in 1902 an enterprising local businessman managed to obtain a concession to supply Linköping with electricity. He started supplying electricity to the town in the autumn of 1903—17 years after the first proposal to investigate electric lighting had been put forward.[9]

In many other towns having gasworks, the establishment of electricity was delayed in the same way as in Linköping. This can be seen by comparing the introduction patterns of gas and electricity. As grid-based systems, both required major initial investments in production and distribution systems, which meant that the best markets for both existed in larger towns, where many potential customers lived close together and maximum economies of scale could be achieved. The pattern of events associated with the introduction of gas was also precisely as expected. The four first gasworks were built in the four largest towns, after which it took only 13 years before all but two of the other 20 largest towns had built gasworks.

The pattern for the introduction of electricity is completely different, due to the resistance from gas interests. Of the four largest towns at the time, Malmö was the third town in the country to have an electrical plant, Stockholm the twelfth, Gothenburg the seventeenth, and Norrköping the forty-eighth. In 1905, 20 years after the country's first electrical plant opened, seven of the twenty largest towns in the country still had no electricity.[10]

The Outcome

In the long run electrification could not be stopped. The introduction of efficient metal-filament incandescent lamps in the 1910s was one decisive reason electricity beat its competitors. Another important factor was the huge increases in the prices of imported coal (and thus gas) and kerosene that occurred during World War I (see Fig. 2). The price of electricity increased only marginally because it was produced mainly by domestic hydropower. This, of course, made electric lighting even more economically competitive.

By 1920 almost all urban households had adopted electric lighting. In the countryside, however, kerosene lighting had a significant market share until the 1940s. This was because, since rural electrification was much more costly and took much longer to accomplish than urban electrification,[11] many households were not yet connected to an electric network.

The Struggle for the Cooking Market

Long before the struggle for lighting ended, the gas industry became interested in two new markets: stoves and engines. In the middle of the 1880s, many Swedish gasworks actively encouraged these new applications through propaganda and new, differentiated gas tariffs. The gasworks were motivated by two main reasons. First, they wanted to ensure their continued existence in the face of the threat offered by the incandescent electric lamp, and second, engine gas and cooking gas (which were the terms used) were used mainly during the day, with consumption being more or less independent of the time of year. Any increase in these applications would therefore help to even out the load on the gasworks, thus making better use of capital.

Gas engines had only a brief popularity. Between 1895 and 1910, engine gas accounted for about 10 percent of total gas consumption, but during the 1920s gas engines quickly lost out to better and less expensive electric motors.

Conditions were much more favorable for cooking gas. By about 1910, it held the largest sector of the gas market. Existing wood stoves, however, were used not only for cooking but also for heating the kitchen during the winter. Therefore early gas cookers could not replace the wood stoves, but merely complement them, as illustrated by Figure 3. They were simple items, having one or two burners, and were mainly used during the summer. Gas stoves with an oven were very uncommon prior to 1910.

The competitiveness of gas stoves improved greatly around this time as a result of two external factors. One was the rising price of wood, caused by increasing

Figure 3. Gas cooker on top of a traditional wood stove. (Photo from the turn of the century)

demand from the pulp and paper industry. In the mid-1920s the cost of fuel for a wood stove, used only for cooking, was about three times higher than that of a gas stove. Furthermore, a gas stove was quicker, easier to control, and easier to use.[12]

Another important factor behind the growth in the use of cooking gas was the introduction of central heating. From 1910 onward, most new apartment buildings incorporated central heating systems, and by 1945 about 75 percent of the apartments in the larger towns had them. The introduction of central heating meant that wood stoves were no longer needed to warm the kitchen, thus eliminating its final competitive edge over the gas stove.

During the interwar years, the wood stove was (at least quantitatively) the main competitor of the gas stove. However, by the 1920s a competitor that the gasworks feared much more than the wood stove was already making its appearance—the electric stove. In order to understand why the electric stove was introduced at this time, we need to start with a brief background sketch.

By 1910, industry had become the major user of electricity, consuming about 90 percent of all electricity. However, domestic consumers were a much greater financial influence on the power and electric companies than their consumption might indicate, because they paid ten times more for their low-voltage electricity than industry did for its high-voltage electricity.[13] The importance of domestic subscribers became particularly apparent during the severe depression after World War I, when the use of electricity in industry fell by 30 percent over a period of a few years, while domestic use continued to increase.

It is against this background that we should view the strong interest of the electric industry in increased domestic use of electricity. In the 1920s, domestic apparatus, and stoves in particular, were felt to be of major importance.[13] Thus, from 1920 to 1960 an intensive competition for the cooking market took place. Three means of competition were employed in this struggle: performance, propaganda, and pricing.

Performance

The efficiency of stoves (expressed by the ratio of heat supplied to energy consumed) was an important cost factor, exactly as it had been for lamps. Ovens, in particular, wasted energy, since they were poorly sealed and lacked thermal insulation. Electric stoves suffered most from this drawback, because electric energy was more expensive. Spurred by this deficiency, manufacturers of electric stoves developed new, efficient ovens by the beginning of the 1930s. These manufacturers were also the first to realize the importance of the external appearance of their product. As a result, they started to manufacture stoves with white enamel surfaces and bright chrome fittings. It was not long before the competing gas and wood stove manufacturers followed their example.

A serious hurdle for electric cooking was that the majority of domestic consumers were connected to direct-current (dc) systems, which were designed for lighting, but not for the higher voltages required for cooking. Therefore, at the end of the 1920s, the electric companies started a changeover from dc to ac. This conversion required a massive capital investment and was not completed until the 1960s.

Another important factor in the competitiveness between gas and electric stoves was the improvement in the production and distribution systems. The conversion from dc to ac supplies in urban areas was carried out at the same time as major changes in the national electrical system. Progressive integration and standardization, together with the development of massive hydropower resources in the north of the country, resulted in significant reductions in the cost of electricity.[14] Compared to this, advances in the gas sector were considerably more modest. However, the efficiency of the actual process of producing gas continued to improve, with overall efficiency of the gas industry reaching more than 80 percent in 1950, as against about 65 percent at the beginning of the century.[15]

Propaganda

The second point of competition for the two energy systems was propaganda. As early as the 1880s the gas companies were publicizing gas for cooking. During the 1910s, it was common for gas companies to open permanent displays, where stoves and other gas apparatus could be demonstrated and sold. In some cities home consultants were employed as demonstrators to hold courses and give lectures on cooking on gas stoves. They also visited new subscribers in their homes and instructed them on how to use their new stoves. After World War I, many electric companies followed the example of the gas companies, opening permanent exhibitions and distributing brochures.[16]

On the national level, both the electric and gas industries developed internal cooperation and exchange of experience through the Association of Swedish Electric Utilities, which was founded in 1903, and the Swedish Gasworks' Association, founded in 1916. Both associations produced advertising material, which was available to their individual member companies. In 1927 the Association for the Rational Use of Electricity (FERA) was founded by power companies and local distributors as well as manufacturing firms such as ASEA. FERA's main objective was the dissemination of information on all the uses of electricity. It also produced brochures and other informational and advertising material aimed at different categories of users (see Fig. 4). The association also employed two home consultants who traveled around the country arranging courses in "electric cooking" for housewives. No association equivalent to FERA was formed by the gas industry, mainly because there was no national manufacturing company of gas equipment of any great importance.[17]

Pricing

The third competitive element was pricing. We have described how and why the gas companies introduced differentiated gas tariffs in the 1880s to encourage the use of both cooking and engine gas. These tariffs disappeared after World War I, simply because there was nothing left to differentiate between, since two of the three previous divisions, lighting and gas engines, no longer existed. However, the electric industry, having learned from the gas industry, began using pricing as an important means of competition, especially when entering new markets. The principles of such

Figure 4. Poster for promoting electric cooking, produced by FERA in 1941.

pricing were formulated clearly by Carl Rossander, a professor of electrical engineering at the Royal Institute of Technology in Stockholm, in a lecture given to the Association of Swedish Electric Utilities in 1925:

> Apart from the abnormal conditions during the war, the price of electric current for lighting in Sweden during recent years has generally been of the order of 30–40 öre/kWh, at which price the electric lamps (and particularly, of course, after the invention of the metal filament lamp) are economically superior to virtually all other light sources, while the price of this electricity is fully satisfactory to the electric companies. The price of electricity for small motors is generally one-half to two-thirds of this, which price is sufficiently low to allow electric motors to compete successfully with other forms of small motors and engines such as gas and kerosene engines, while experience has shown that the electricity companies can generally supply motor current at this price.
>
> If, on the other hand, electric energy for boiling and other food preparation is to be able to compete seriously with wood, gas, etc., then it would be necessary for the price of current not to exceed about 10 öre/kWh or thereabouts, even after making allowance for the advantages of electric cooking in terms of convenience, cleanliness, etc. Conditions will be even more unfavourable if electric energy is to be used for space heating, for which the price in general should be of the order of 2–3 öre/kWh. It is easy to understand if the majority of electric companies do not feel able to supply energy at such low prices.[18]

In other words, Rossander claimed that the necessary level of competitiveness of electricity in different markets determined its price. This was a controversial idea. The electric companies had a monopoly but claimed that their tariffs reflected the cost of supplying electricity to their customers. The high price of electricity for lighting, for example, was justified by the unfavorable loading. However, it seems obvious that the electric companies exaggerated this factor and made a considerable profit from the lighting market.[13] These substantial profits then allowed them to subsidize the introduction of electric stoves during the 1930s with extremely low prices.

Encouraging households to adopt electric stoves was difficult. Including the necessary new saucepans (with flat bottoms) and installation, an electric stove represented a sizable investment. Therefore, operating costs had to be kept low in order to encourage consumers to lay out the money. Several of the more aggressive electric companies introduced new tariffs, supplying electricity for stoves at about 8 öre/kWh. They justified this (e.g., to their lighting subscribers, who were being charged 35 öre/kWh) by claiming that electric stoves resulted in much more uniform loading on the system than lighting did.

However, this was simply not true. A study of electric cooking carried out by the State Power Board in 1928 includes a load diagram from a Stockholm suburb for a winter day in 1926 that shows a very marked peak in demand by stoves immediately after 5 P.M., at which time the lighting load was at 90 percent of its maximum value.[19] In other words, the stove load was not at all favorable. The fact that lighting subscribers subsidized the introduction of electric stoves in this way was never openly admitted by the electric utilities.

The Outcome

In the 1950s electric stoves made considerable gains in urban areas. One of the reasons for this was that a lot had happened in terms of stove development. For example, hotplates had considerably higher ratings, and therefore cooked faster than before. Ovens now incorporated thermostats and good thermal insulation, so that they were quite economical. Prices, too, had been reduced as a result of long production runs. A second important factor was that the old dc networks in the larger town centers had by now been replaced by ac networks capable of supplying stove loads. Finally, while the average price of electricity had been halved in real terms between 1925 and 1950, the price of gas remained the same. As a result, many owners of gas stoves switched to electric stoves during the 1950s. For many gasworks this loss of cooking customers was a fatal financial blow, forcing them to go out of business. Of the 37 Swedish gasworks operating in 1950, only 8 remained in 1980.[1]

As in the case of lighting it took a long time for electric stoves to capture the rural stove market, the rate of adoption depending largely on how quickly the rural electrical networks were upgraded from dc to ac. By the end of the 1960s, however, the majority of rural households were using electric stoves.[11]

Conclusion

The struggle for the lighting and stove markets clearly illustrate how competition can encourage technical development and in particular the development of more energy-efficient designs. Sometimes, however, the competitive advantage of energy-efficient appliances was not fully understood by the energy suppliers. For example, many directors of electric companies regarded the metal-filament lamp as a serious threat when it first appeared because, for the same light output, it used less than half as much electricity as a carbon-filament lamp. As subscribers changed to the new lamps their use of electricity therefore decreased considerably.

Between 1905 and 1910 a substantial slowdown occurred in the previously rapidly growing use of electricity. In 1910 there was a lively debate among managers of electric companies, many of them expressing great concern about the metal-filament lamp. Others, however, were more farsighted and reassured their colleagues that "the time will come . . . when the electric works will owe a debt of gratitude to the current-saving lamps for a considerable increase in the use of electricity."[20] Today, a similar kind of ambiguity vis-à-vis energy-efficient technology can frequently be seen among energy suppliers.

The outcome of these struggles has depended not only on technical development but also on the political and economic strengths of the parties concerned. During the struggle for the lighting market, gas interests had the most political influence, and in many places were able to prevent the formation of electric companies for a long time. On the other hand, during the struggle for the stove market, the strong financial status of the electric companies played an important part in deciding the outcome.

The importance of financial strength is related to the advantage that established energy systems always have over new energy systems. From the consumer's point of view, a change of energy system represents a considerable investment in new equipment and, if it is a grid-based system, in new service connections. Good examples of this can be seen in the conversion from gas to electric lighting and from a wood to a gas stove.

In such conversions, the new energy system must be offered with favorable introductory terms so the change is attractive to the consumer. In the Swedish case, the electric companies, with their large financial resources, could offer significant tariff reductions at the time when they wanted to enter the stove market.

Once the consumers have made the necessary investment in new equipment and connections, there is little chance that they will give up the new system. Prices will have to rise significantly before they will even consider changing again.[2] We can find many contemporary analogies to the events and ideas given in this chapter.

Notes

1. A. Kaijser, "*Stadens ljus—Etableringen av de första svenska gasverken*," in Linköping Studies in Arts and Science No. 4, Chap. 9, 1986.
2. A. Kaijser, A. Mogren, and P. Steen, *Att ändra riktning—Villkor för ny energiteknik* (Stockholm: Allmänna Förlaget, 1988). English Transl. 1991: *Changing Direction—Energy Policy and New Technology* (Stockholm: National Energy Administration, 1991), p. R5.
3. A. Ahlsell, "Om förhållandet mellan elektrisk belysning och gasbelysning," in *Ingeniörs-Föreningens Förhandlingar 1883* (Stockholm: 1883), pp. 47–50.
4. H. Söderberg, *Sekelskiftet*, ed. D. Hjorth (Stockholm: 1964), p. 39.
5. N. Rosenberg, *Perspectives on Technology* (Cambridge, England: Cambridge Univ. Press, 1976), p. 205ff.
6. H.-J. Braun, "Gas oder Elektrizität? Zur Konkurrenz zweier Beleuchtungssysteme, 1880–1914," *Technikgeschichte*, Vol. 47, No. 1, 1980, pp. 1–19.

7. A. Bright, *The Electric Lamp Industry* (New York: MacMillan Co., 1949), Chap. 6.
8. F. Hjulström, *Sveriges elektrifiering* (Uppsala, Sweden: 1940).
9. O. Holmqvist, *Linköpings gasverk 1861–1936* (Linköping: 1936).
10. H. Lindblom and G. Bergqvist, *Kommunal affärsverksamhet i de svenska städerna* (Stockholm: 1924), p. 22ff.
11. J.-E. Hagberg, *Tekniken i kvinnornas händer. Hushållsarbete och hushållsteknik under tjugo-och trettiotalen*, Linköping Studies in Arts and Science, No. 7, 1986.
12. *Stockholm's gasverk 1853–1928* (Stockholm: 1928), p. 85.
13. J. Körner, *Sveriges elektricitetsverksindustri* (Stockholm: 1928).
14. Statens Vattenfallsverk, *Vattenfall under 75 år* (Stockholm: 1984).
15. *Gasverksföreningens årsbok 1951* (Stockholm: 1951).
16. *ERA*, No. 4, 1937, p. 56.
17. *ERA*, No. 23, 1952, p. 139.
18. C. Rossander, "Om tariffer för elektrisk energi," *Svenska Elverksföreningens Handlingar 1926*, No. 3 (Stockholm: 1926).
19. *Elektrisk kokning*, Tekniska Meedelanden från Kungl. Vattenfallsstyrelsen, Series E, No. 12, (Stockholm, 1928), p. 54.
20. *Teknisk Tidskrift*, Elektroteknik, Häfte 2, 1910, p. 28.