THE BRITISH ELECTRICAL

1875 - 1914

by

I.C.R. BYATT

[MT 1962]
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<td>Telegraphic Journal</td>
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<tr>
<td>E.R.</td>
<td>Electrical Review</td>
</tr>
<tr>
<td>Elect.</td>
<td>Electrician</td>
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<tr>
<td>Carke's</td>
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<td>Manual</td>
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<td>E.T.D.</td>
<td>Electrical Trades Directory</td>
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<tr>
<td>B.P.P.</td>
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<td>E.J.</td>
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Abstract.

This is a study in the beginnings of an industry. The electrical industry was chosen for two reasons. Firstly its story is that of the beginnings of the substantial economic application of a new technology. Secondly it was an important industry in the British economy at the time. It has sometimes been argued that the slow growth of this industry is one of the reasons for the slow growth of the economy. Thus the material has been principally organised around two matters, innovation and technical progress, and the allegedly slow growth of this industry in Britain before 1914.

The electrical industry has been widely defined. I have taken the three principal uses of electricity at the time, lighting, traction and (non traction) motor power, and looked at the introduction and early growth of electrical methods. Thus the industry is defined within technological boundaries. I have included electricity supply, electric traction and the manufacture of electrical machinery - all of which could be treated as separate industries. Thus I have dealt with heavy electrical engineering, and have ignored the light electrical engineering of the time, which was connected with the use of electricity for telegraphs and telephones. Electrochemistry has also been ignored as the scarcity of cheap water power in Britain made it unlikely that it would develop to any considerable extent in Britain.

Roughly speaking, electric lighting, traction and power were new methods of providing existing products, light, rail transport (by

1. Principally factory motors. For convenience electric power is generally used to refer to non traction electric motor power.
train or tram) and factory turn power. Therefore in Chapters 1, 5 and 6 I have looked at the cost of the new electrical methods compared with existing methods, or more accurately have tried to see what resources would be saved by using electricity.

However one cannot expect the only reason why new technical developments were (or were not) adopted, or adopted quickly or slowly to be that they did (or did not) save resources. Thus I have looked at other variables, like the rate of growth of the economy, the timing of cyclical fluctuations, legislation and relations between business and technology. Attempts have been made to illuminate the English experience by contrasting it with the situation in the United States.

In Chapter 1 I have argued that the principal reason for the apparent failure of the attempt to establish electric lighting in this country in the early 1830s was the low price of gas. As the price of electricity relative to gas fell during the 1830s and 1890s electric lighting became more widely used. However it does not seem to have been until the introduction of the metal filament lamp in the years 1908 - 10 that electric lighting had the same advantage, relative to gas that it seems to have had in the United States as early as the middle 1830s. Also the slower rate of urbanisation in Britain compared with the United States, and the timing of the cycle affected the rate of adoption of electric lighting. Chapters 2 and 3 deal with the use of electric lighting when electricity was provided from a central station.

In Chapter 5, Section 1 I have argued that electric trams saved resources, but that their adoption was delayed in the early and middle
nineties' by the effect of the Tramway Act, the unprofitability of horse trains, the lack of interest of home electrical manufacturers, the attitude of the municipalities and their relations with joint stock enterprise. I have argued that the boom in electric traction 1897 – 1903 was stimulated by the building cycle, the rising demand for transport, and the entry of American firms. After 1903 the boom died away as demand had been satisfied. Demand rose only slowly as tramways do not appear to have stimulated suburban building in the short run. In Section 11 I have discussed urban electric railways, particularly the London Underground. I have stressed the importance of American engineering and enterprise in promoting resource saving innovations. I have also argued, although the matter is complicated by questions of lay out and fares that the low profitability of urban electric railways showed that demand was limited. In Section 111 I have tried to show why the suburban lines of main line steam railways were only slowly electrified. I have argued that electric traction would have only been adopted had it been capital saving. Where tramway competition made capacity redundant, electrification was not worth while.

In Chapter 6 I have examined factory electrification. My tentative conclusions are that while electric transmission of power was probably on balance fuel saving, its capital costs were greater than those of mechanical transmission before 1901 – 05, although after that they were, on balance, as low. However the evidence suggests that substantial resource saving would only have accrued from electrification if, it had taken place in conjunction with other changes in the techniques of production. However
there are enormous difference between industries and an important reason for the apparently slow rate of factory electrification in England is that its advantages were perhaps least in two of the great power using industries, textiles and mining.

In addition Electricity supply and the manufacture of electrical machinery have been dealt with in some detail. Their combined influence on the cost of electrical methods was very great. Costs in these sectors fell regularly as the process of innovation continued. The prices of other inputs of electric lighting, power and traction generally fell less than those of the products of these two sectors. Also they held a central position in the process of innovation. Most innovations were adopted on their initiative, and they were responsible for making adoptions to other machinery and to buildings.

The electricity supply sector is dealt with in Chapters 2, 3, 4, 9 and 10. In Chapters 2 and 3 I have looked at the general development of electricity supply largely by discussing the major innovations and trying to see how their adoption might have reduced, or did reduce, costs. I have also tried to put the story of the beginnings of electricity supply on a sound statistical basis by constructing time series of investment in electricity supply and sales of electricity for lighting power and traction. Chapter 4 deals with the attempts substantially to increase the area of supply and shows how the only successful attempt involved some important innovations. Particular attention has been given to developments in electrical machinery. This is partly because the makers of electrical machinery have also been dealt with in detail.
Chapters 9 and 10 are on the control of electrical utilities and their pricing policy. It has often been said that legislation delayed the development of the industry and Chapter 9 is an attempt to examine the inadequacies of the public utility control at the time. It is shown both that it worked very crudely, and that it had a tendency to keep profits low by keeping costs high. In Chapter 10 it is shown that the usual pricing system of electricity supply undertakings was based on a theoretical misconception, and that it could lead to distortion of resources. The pricing policy of electric traction undertakings is shown to be perverse because of the attempt to help workmen to live in better houses.

The makers of electrical machinery are considered in Chapters 7 and 8. Three important issues have been dealt with, the process of innovation, the question of new entry into this new industry, and the workings of competition. The three are intimately connected. Innovations in machinery often involved the entry of new firms. The workings of competition taken together with the nature of the cyclical fluctuations in the demand for electrical machinery, reacted on innovation. The speed of innovation affected the way competition worked. I have also discussed the effect which the British capital market had on the electrical manufacturers.

Chapter 11 contains two sections. One is a summary of the process of innovation in the whole electrical industry. The other is a sketch of the financing of investment in electricity. I suggest that borrowing was only difficult in some sectors.

The methods of calculating some of the Tables are in an Appendix. There is also a Technical appendix explaining some of the engineering matters.
Chapter 1.

Electric Lighting: the early days.

One of the earliest ways in which it was thought electrical energy could be used was in electric lighting. As early as 1808 Sir Humphrey Davy demonstrated that it could be used for arc lighting. He produced an arc of intense brilliance by touching and separating two carbon rods connected to a huge primary battery. He also shewed that various materials could be heated to incandescence by the passing of electrical currents and concluded that carbon and platinum wires could probably be used in this way to make a light. From these two forms of light were developed the arc and incandescent lamps respectively, which were used up to 1914 for lamps of large and small intensity. The arc lamp has subsequently been replaced for all but a few uses, but the incandescent lamp is still used for much interior lighting. In Davy's time there was no chance of electric lighting being used commercially. The incandescent lamp had still to be invented, and while the only source of electricity was the primary battery, the cost of electric lighting was prohibitive. The solution to this problem was the invention of a dynamo, but many years passed after the discovery of electro-magnetic induction by Faraday in 1831, before such a source of

2. Ibid. P.75.
of energy could be used to produce electricity at a cost which made electric lighting commercially possible. A small generator was constructed by Pixii a year after Faraday’s discovery, and larger ones followed at intervals. But the important developments were made in the sixties and early seventies. In 1860 Faccinotti developed a ring wound armature, but this important development was largely overlooked. In 1866–7 Werner Siemens, Wheatstone, Varley and Wilde, working from an idea of Wilde’s, constructed generators which operated on the principle of self excitation. This meant that they could generate the current for their own fields and made the construction of powerful but relatively small – dynamos possible. This very important step forward was consolidated by Gramme who in 1870 rediscovered ring winding and combined it with the principle of self excitation in the construction of a dynamo which was the first to have good commercial prospects. Three years later von Hefner Alteneck redesigned the Siemens dynamo which had the same economic advantage as that of Gramme.

The question of providing cheap current having been solved, the other leg of the basic technical problem, the construction of good lamps, could proceed without delay. Some work had been done before the 1870s on arc and incandescent lamps but it had not been very successful, nor had it been pursued with such energy as was to go into developments in the late seventies. Davy had used soft pieces of charcoal for his

2. Ibid.
lamp and these were rapidly consumed by the passage of the current. More suitable electrodes had to be devised which burnt more slowly and also some method of maintaining an arc of the same length when the electrodes were consumed. In 1865 J.B.L. Foucault had produced a self regulating arc lamp and in the 1860s this had been improved by the solenoid controlled clockwork mechanism of V.I.M. Serrin.\(^1\) In 1876 a Frenchman, Carre, produced carbon electrodes which lasted for a reasonable time. In the late seventies a large number of regulating mechanisms were also devised.

In the 1840s the invention of the Danielli, Grove and Bunsen primary batteries aroused a burst of activity directed towards producing an incandescent lamp. But the inventors were handicapped by their inability to produce a good vacuum. Without it the incandescent element fused and the activity of the 40s subsided without having achieved anything. But in 1865 Sprengel invented the mercury vacuum pump and in 1875 Sir William Crookes obtained an almost perfect vacuum with it. This together with the new dynamos of the early 70s induced another, this time successful, burst of inventive activity. J.W. Swan, who had done some work on the incandescent lamp in the 40s, returned to it, working in conjunction with C.H. Stearn, who had been making experiments with a vacuum pump and by December 1878 had shown a practical incandescent lamp

1. J.A. Fleming. *op.cit.*, p 150
2. J.A. Fleming. *op.cit.*, p 150
to the Newcastle-upon-Tyne Chemical Society. 1879 he spent improving the filament and the exhaustion process and by early 1880 he was convinced that the lamp was a commercial proposition. Edison had started work on inventing an incandescent lamp in the autumn of 1877. At first he attempted to use a platinum filament but this lamp, brought out in October 1879, was not a success. However, one year later he produced a successful carbon filament lamp. Other inventors were working on an incandescent lamp at the same time; in England St. George Lane-Fox produced a lamp with filament of platinum - iridium in 1878 but two years later followed Edison and Swan with a carbon filament. In the United States Hiram S. Maxim and William Sawyer worked on the lamp and by the end of 1880 Maxim had produced a successful one.

Those developments and inventions had brought electric lighting to the threshold of commercial development. Now we can consider this.

Arc lighting was used first. It had even been used at South Foreland Lighthouse as early as 1853, but it had been both expensive and technically unsatisfactory. However in 1878 Trinity House made experiments with the new Gramme and Siemens dynamos. The Siemens machine worked particularly well; they cost less than a fifth of the cost of the South Foreland type dynamos and gave 5.6 - 4.4 times the light. Electric lighting was used at the Lizard in 1879 and cost only 24% of the amount oil lighting had cost. At South Foreland it had cost three times as much.

2. H.B. P 70.
Lighthouses provided the most favourable conditions for arc lighting. Compared with other sources of lighting, oil and gas, arc lights provided a relatively cheap light if very great intensity was required. But for small powered lamps gas was cheaper.

Apart from rather special cases like lighthouses, the obvious uses for arc lamps was for lighting streets, open spaces, factories and large public buildings. In the second half of the 1870s it was more expensive than gas for these purposes. A high candle power arc lamp, say above 1000 candle power, was cheaper than a gas lamp of the same power. But as the power of the arc was reduced costs fell very little.

Illumination, however, is not simply a question of the candle power of lamps. The illumination given out by a lamp diminishes by the square of the distance between the lamp and the object lit. A few high candle power arcs would give pools of light with semi darkness in between. A large number of low powered lights giving the same average illumination would give a much more even distribution of light. If arc lamps were to replace gas lamps and give the same minimum illumination, the average illumination over the whole area lit would be much greater. It follows that the greater the average illumination required the more advantageous it would be to arc lighting.

In the 1870s lighting standards were still fairly low. The streets in the centre of towns were lit by low powered (often 16 candle
Lighting was being improved by the introduction of new, higher powered gas burners made by Bray and Sugg, giving 150 - 250 c.p. But although towns were at the time prepared to pay more for some more light, the jump to the amount of light which fairly even arc lighting would entail was considerable.

For interior illumination the situation was more favourable to arc lighting, because more light was required and because the inside walls by providing some reflection helped high powered lights. In factories it could, in some cases, reduce costs by increasing the productivity of other resources. Better lighting could improve the quality of work or speed up tasks. Overhead lights out of the way of the machinery reduced the risk of accidents. In theatres and indoor places of assembly arc lighting did not raise the temperature. In any building where there was a fire risk arc lamps were safer than gas.

The quality of the light given by arc lamps was open to some objection. It was harsh, bluish in colour, and threw deep shadows. Its colour gave, human complexions an unpleasant appearance. It also flickered in an unpleasant fashion. On the other hand it gave a whiter light than the yellow gas lamps. Thus it was particularly useful in

1. The incandescent gas mantle was not introduced until 1885 and scarcely used until the late nineties. The 16 c.p. gas burner would give appreciably less light than the modern 25 watt bulb.

2. Sugg marketed the Siemens regenerative gas burner.

3. "Twinkle, twinkle, little Arc
   Sickly, blue, uncertain spark;"

establishments where colours had to be distinguished, for example in cloth factories and drapers' shops.

Even after the improvements in dynamos in the 1870s arc lighting was much too costly to be used, except for special functions, like lighthouse lamps. This is clear from an examination of the cost of Siemens arc lighting. Siemens Bros. were one of the pioneers and their dynamos were perhaps the best and the cheapest on the market. They could draw on the engineering resources of Siemens and Halake of Berlin, with whom they were very closely associated. Sir William Siemens was a very able engineer indeed, and in the late seventies he made several important improvements to arc lamps. He saw that the significance of arc lighting was that it could produce a light of great intensity more cheaply than gas. To give the best results arc lamps were placed on posts, 60 - 80 ft. high. Although in 1879 and 1880 Siemens arc lamps were installed in a number of places, they were, allowing for all the difficulties of measurement, very much more expensive than gas lamps. The reason for this was that, like most of the early arc lighting pioneers Siemens used a dynamo for each arc lamp. Had this continued arc lamps would have been very rarely used.

Eventually arc lighting costs were substantially reduced when several lamps were run from each dynamo. This was successfully achieved

1. For details of the relations between Siemens Bros and Siemens & Halake see J.D. Scott. Siemens Bros. 1839 - 1896. London 1956.
by the use of high voltage dynamos. But they had to be developed, and control devices improved so that lamps could regulate themselves individually when all were on the same circuit. Two systems of arc lighting which attempted to reduce costs by spreading dynamo costs over several lamps were introduced into Britain in the years 1873 - 1880. One came from France; one from the United States; one was a failure; one was very successful.

The former, and the first to come to this country was the arc lighting system of Paul Jablonskoff, a Russian army engineer who had settled in France. His system was simple, robust and inexpensive to manufacture. In the place of the usual lamp with its expensive clock-work mechanism he adopted a "candle" type lamp. It worked at low voltage and six "candles" were connected to each circuit. He used a Gramme alternator wound so that it could feed several circuits. Thus Jablonskoff was able to use an existing type of dynamo and spread the heavy dynamo and prime mover costs over many lights.

The candle power of the "candles" was low - 150 - 200 c.p. This was useful, for the improved gas lamps coming in at this time were of

1. See Technical Appendix [51] for details, and an explanation of the electrical terms used.

2. The "candle" consisted of two rods of carbon placed parallel and separated by an insulating strip of kaolin. The arc started at the top and travelled downwards as the carbons were burnt and the melted.

3. It was effectively a polyphase machine, six "candles" being connected to each phase. See Technical appendix.
this power. But unfortunately the use of arc lamps of such low power sacrificed the special advantages of arc lighting. For Jablochkooff's "candles" were more expensive than the new gas burners.

Table 1.

Costs of Jablochkooff arc lighting and gas lighting.

1. Cost of Jablochkooff arc lighting

Total cost except for carbons, per lamp hour d.

<table>
<thead>
<tr>
<th></th>
<th>3600</th>
<th>1740</th>
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<tbody>
<tr>
<td>Costs on the Embankment</td>
<td>3.8</td>
<td>4.4</td>
</tr>
<tr>
<td>actual running &amp; estimated capital costs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ditto plus estimate of extra cost to make installation permanent</td>
<td>4.3</td>
<td>5.4</td>
</tr>
<tr>
<td>ditto estimates for a 50 light station, the biggest one built</td>
<td>2.9</td>
<td>2.2</td>
</tr>
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2. Carbon costs per lamp hour

1877, 4.7d.; late 1879, 2.0d.; late 1880, 1.5d.

3. Cost of Sugg gas burners.

Total cost per lamp hour d. assuming price of gas was 3/6d per 1000 cubic feet.

<table>
<thead>
<tr>
<th>Hours lighting per annum</th>
<th>3600</th>
<th>1740</th>
</tr>
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<tbody>
<tr>
<td>155 c.p. burners</td>
<td>2.2</td>
<td>2.5</td>
</tr>
<tr>
<td>265 c.p. burners</td>
<td>3.7</td>
<td>4.0</td>
</tr>
</tbody>
</table>

Sources: T.W. Keates. Metropolitan Board of Works.
Sugg in evidence to the 1879 Select Committee.
As Table 1 shows carbon costs alone were little less than the cost of equal power gas burners, thus although capital costs were spread widely and kept down by simple apparatus, there was only a small gap between carbon and total gas costs for other electric lighting costs to fit in. Capital and fuel costs would have fallen in time as cheaper and more efficient dynamos were made. But it is unlikely that carbon costs could have been further reduced, or that more than 60 lamps could be connected to one generator.

Jablochkoff arc lighting was a failure because it did not use the comparative advantage of arc lighting — the ability to produce an intense light very cheaply. But it was a bold attempt to produce a commercially viable system. Economic considerations were clearly to the fore. Using an existing generator and a simple rugged lamp might in other circumstances have been a great success. As it was, it was too crude to be further developed to the point where it might become cheap enough. Using a Gramme dynamo committed Jablochkoff to low voltages, which were inefficient. The candle was simple since it required no complicated food mechanism, but it needed a.c. which was then more costly than d.c. Because of poor insulation, which could not be improved, it was wasteful of current.

Jablochkoff arc lighting was exhibited at the West India Docks in 1877. However the first important installation was in Paris; the Avenue de l'Opéra was lit by Jablochkoff "candles" some time before a permanent installation was made in this country, and many Englishmen went

to Paris to study it. In 1878 the Société Générale de l'Électricité, the manufacturers of the "candles", was able to persuade the Commissioners of Sewers of the City of London to try the new lighting for a period of three months on Holborn Viaduct. The experiment was not successful; there were many breakdowns and it was very expensive. At the end of three months an offer to continue the lighting at half the experimental price was refused. However, in December 1878 the Metropolitan Board of Works also decided to try the light and 20 lamps were put on the Embankment. This installation was more successful. It lasted for several years and the number of lights was increased to 40 in March 1879, 50 in October 1879 and 60 in January 1880. After 2½ years there had not been a single breakdown. In 1879 several small Jablochkoff installations were made, and at the end of the year it was estimated that 165 Jablochkoff lamps were in use nightly in England.

The second, and successful attempt to reduce costs by the use of multi-arc dynamos was that of C.F. Brush. He saw that the key to the problem was the dynamo and developed a high voltage machine which would serve several arc lamps in series. For his lamps he chose a power of 1000 c.p. This was in between the very high power of Siemens lamps.

3. For a detailed account of Brush's work see H.C. Passer, op.cit. Chap. 2.
4. See Technical Appendix.
5. They were 2000 nominal c.p. Actual candle power was about half the nominal value as nominal candle power was obtained by putting the carbons in an abnormal position.
(3000 c.p.) and the small power Jablochkoff "candles." Thus the relative advantages of arc lighting were kept, but it was more suitable for general lighting purposes than the Siemens lamp. The Brush lamps were simply regulated and robust. The light was not as regular as that of some other lamps with more complex regulating mechanisms, but Brush improved matters by manufacturing his own carbons, which were said to be the best on the market. By using a double carbon lamp which burned for 16 hours labour costs were reduced as carbons no longer had to be changed during the night. Brush's dynamo was also more economical than most. An additional advantage of using high voltages was that cable costs could be very much reduced.

As Table 2 shows Brush's innovations reduced the cost of arc lighting to a point far below that achieved by Siemens. In January 1880 the Anglo-American Brush Electric Lighting Corporation was formed. The commercial story of arc lighting in Britain dates largely from then.

Incandescent lighting was used commercially very soon after arc lighting. Unlike arc lighting the power of the lamp was small, the same as that of the existing ordinary gas burners. This was intentional. Although Swan's first lamps were about 25 c.p. he soon reduced them to 16 c.p. Thus incandescent lamps fitted directly into the existing lighting market and the costs of gas and electric incandescent lights were directly comparable in a way that gas and arc lighting costs were

2. Henceforth referred to as Brush.
Table 2.

Costs of various arc lighting systems.

1. Initial cost per lamp (excluding erection costs)

<table>
<thead>
<tr>
<th></th>
<th>Jablochkoff</th>
<th>Siemens</th>
<th>Brush</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine</td>
<td>£8.3</td>
<td>£120.5</td>
<td>£30.3</td>
</tr>
<tr>
<td>Dynamo</td>
<td>£13.0</td>
<td>£114.0</td>
<td>£25.0</td>
</tr>
<tr>
<td>Lamps</td>
<td>£10.0</td>
<td>£21.0</td>
<td>£22.3</td>
</tr>
<tr>
<td>Cables</td>
<td>£19.5</td>
<td>£34.6</td>
<td>£12.3</td>
</tr>
<tr>
<td></td>
<td>£56.3</td>
<td>£350.1</td>
<td>£89.9</td>
</tr>
</tbody>
</table>

2. Running costs per lamp hour d. (Labour is excluded. If included Brush results would become even more favourable.)

<table>
<thead>
<tr>
<th></th>
<th>Jablochkoff</th>
<th>Siemens</th>
<th>Brush</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel</td>
<td>£0.69</td>
<td>£2.65</td>
<td>£0.69</td>
</tr>
<tr>
<td>Carbons</td>
<td>£1.33</td>
<td>£5.5</td>
<td>£2.27</td>
</tr>
</tbody>
</table>

| Number of lamps per dynamo | 20 | 1 | 1 | 1 | 16 | 32 |
| Candel power of lamps       | 150 | 3000 | 1000 |

Coal prices vary, but this makes little difference.

Sources:

Jablochkoff. T.W. Keats. Evidence to the Select Committee on Lighting by Electricity 1879, corrected to allow for full employment of capacity.

Siemens. Crompton. Electric Lighting for Industrial Purposes

Brush. Electric Light 18 June 1881.
not. But the question of whether people were going to use gas or electric lighting was not entirely a question of their relative costs. Electrical incandescent light had quality advantages. It gave a steady light compared with the wavering light of the gas jet. It did not produce as much heat for a given quantity of light - well lit gas lit rooms became unbearably hot at times. Also gas produced fumes which were unpleasant, and as it burned it vitiated the atmosphere and blackened decorations. An important advantage was that electric incandescent lighting was the only form of light which was not a flame light and thus had a lower fire risk than any other type of light. In buildings with a large fire risk only electric incandescent light could be used. The higher quality of incandescent lighting affected the degree of substitution between incandescent and gas lighting. It was not perfectly elastic because people with different incomes would change from gas to electric lighting at different levels of the price gap (electricity exceeding gas) between them. If the two forms of lighting cost almost the same amount there was little doubt that electricity would be chosen. When Edison made a survey in New York he found that at "gas price" nearly all consumers preferred electric lighting. The amount by which electric lighting costs would exceed gas costs and yet prosper, depended on the excess which people were prepared to pay for this luxury light. But clearly when the price of gas and electric lighting were not dissimilar there would be high elasticity of substitution between the two. If such a price parity could be achieved for electric lighting it would inevitably spread into a wide market. Without achieving this it would satisfy only a small luxury need.
Inventing the lamp was only one step in the introduction of incandescent electric lighting. Existing arc lighting dynamos designed to operate at a constant current were unsuitable, as incandescent lamps required a constant voltage.

Also the type of distribution system used for arc lighting was unsuitable. On a series circuit lights had to be switched on and off together. For street lamps and factory lighting this was not a major disadvantage, but it clearly would have been for incandescent lamps where many more would have to be connected to each dynamo for the light to be sufficiently cheap, and where intermittent use was more clearly desirable. Being able to control lights individually would economise on both capital and running costs.

The only way to do this was to connect lamps in parallel. Parallel connection could however involve very high conductor costs, if the operating voltage was low. The construction of a lamp for a high voltage circuit was more difficult than one for a low voltage. The first lamps ran at 50 v, but lighting costs were much reduced when lamps for 100 v circuits were developed.

1. Capital costs because the probability that all would be switched on together was very small.

2. See Technical Appendix.
The beginnings of the introduction of arc lighting in this country came in 1879. It was a year of lighting exhibitions, and in the course of the year nearly all large towns had exhibitions of arc lighting. Parliament appointed a Select Committee to consider the place of electric lighting in the economy. But although the interest was great, very little had been done and the committee did not feel that the time was ripe to give any general powers to electric lighting companies to undertake public and private lighting.

In 1880 electric lighting started to appear on more than a minute scale. The year began, prophetically enough with the formation of Brush. At first the company was only a sales agency for the American parent but sales of Brush equipment were sufficiently large for it to start manufacturing in this country at the end of the year. By then it had come to share with Siemens and Jablochkoff the first place in the arc lighting market.

Another system of arc lighting became important at the time. R.E.B. Crompton began to make lamps in 1879. At first he followed the

4. Born 1815. Entered the army at the age of 18. Devoted himself to mechanical engineering, particularly road transport. In 1876 he left the army and became a partner in the firm of Dennis & Co. of Chelmsford. He became interested in arc lighting when trying to speed some constructional work he was superintending by working at night. He thought of manufacturing it himself because of deficiencies in the arc lights he used. Further details see R.E.B. Crompton. Reminiscences
usual practice of using a dynamo for each lamp, but following the success of Brush he began in 1880 to make multi arc dynamos. In 1879 his lamp was used in only six places; in 1880 he had at least 24 installations and was said to be unable to produce equipment fast enough. But he had only a small works.

Throughout 1881 the progress continued. Brush seems to have taken the lead. Siemens expanded, but at a slower rate. Jablochkoff lighting was declining in importance and Crompton joined Brush and Siemens in the first place. But Jablochkoff sales were probably rising.

A smaller company, the British Electric Light Co., formed as early as December 1873 to import Gramme dynamos, and which had subsequently brought the patents for the Brockie arc lamp, was also very busy and doubled its office accommodation during 1881. New companies were formed, notably the Electric Light and Power Generator Co., to market the Lontin lamp in England, which had become notable in 1830. 1881 was noteworthy for the electric lighting in the City of London which was sponsored by the Commissioners of Sewers. This was a good opportunity to demonstrate the virtues of electric lighting prominently and on a large scale. The major companies, Brush, Siemens, Crompton and the Electric and Magnetic Co., sent in tenders. Contracts were awarded to

Brush, the Electric and Magnetic Co. and Siemens for a year's lighting which was due to start in April 1881. The Electric and Magnetic Co. were unable to complete their part of the contract, and the lighting for their district of the City was given to the newly formed Electric Light and Power Generator Co., using the Lentin lamps. The lighting of the City put the electric light into the public eye and thus helped to create the conditions for the boom of 1882.

1881 was also a year of demonstrations of incandescent lighting. The early lamps were those of Swan. Early in 1880 when he considered that he had invented a practical incandescent lamp, Swan had got in touch with Crompton. Although Crompton had very recently stated that incandescent lighting was so experimental that it could be ignored, he was impressed by Swan's achievements. Soon afterwards Swan began to manufacture lamps with Crompton as chief engineer to the company. Crompton did contracting work and made generators for the Swan Co.

In the summer of 1880 Crompton demonstrated Swan lamps at Glasgow and in the autumn received an order from the Glasgow C.P.O. Swan installed incandescent lighting in Sir William Armstrong's house. In 1881 several more small installations were made. Some country houses were lit. Ship lighting was undertaken, and the Admiralty convinced that

1. The Electric and Magnetic Co. had been formed to market the imported Jablochko equipment in Britain.
3. In his pamphlet Electric Lighting for Industrial Purposes 1880
5. Edison Swan Electrical Co. Percent of the Lamp.
that incandescent bulbs would be safe enough and tough enough for a man of war. But 1881 was chiefly spent in bringing incandescent lighting into the public eye. It saw the Paris exhibition and this gave Swan a chance to demonstrate his lamps on a large scale. Other pioneers, Edison, Maxim and Lenox-Fox also exhibited at Paris.

In the first half of 1882 a considerable boom seemed to be developing in electric lighting. It was primarily a boom in arc lighting, very largely because of the success of the Brush system. But incandescent lighting also participated. In 1881, superiority of the Brush system had become obvious. Hitherto Brush had both manufactured and sold arc lighting equipment to final consumers. But in 1881 it decided to concentrate on manufacturing. It began to sell concessions to companies giving them the exclusive right to sell Brush equipment in a particular area. The first concession was sold in June 1881. Companies were formed to buy concessions for other areas, and for a year these sales continued at high prices.

Once formed these concessionary companies bought Brush equipment and began to demonstrate it to stimulate sales. Confidence in the future lighting thus rose. New companies wishing to buy Brush concessions found it easy to borrow money and the process continued.

At the same time the municipalities became interested in the possible use of arc lamps for street lighting. In the early days, it was difficult to find out about the desirability or costs of electric lighting.

<table>
<thead>
<tr>
<th>Year</th>
<th>Cash (£)</th>
<th>Shares (£)</th>
<th>Total (£)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1881</td>
<td>Dublin E.L. Co.</td>
<td>1,000</td>
<td>9,000</td>
</tr>
<tr>
<td></td>
<td>Hammond Co.</td>
<td>20,500</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Scottish Brush</td>
<td>10,000</td>
<td>20,000</td>
</tr>
<tr>
<td></td>
<td>Foreign Companies</td>
<td>34,000</td>
<td>20,000</td>
</tr>
<tr>
<td></td>
<td><strong>Total less expenses</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1882</td>
<td>Hammond Co.</td>
<td>7,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>G.W. Electric Light and Power Co.</td>
<td>13,750</td>
<td>15,000</td>
</tr>
<tr>
<td></td>
<td>S.E. Brush</td>
<td>10,000</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Brush Midland</td>
<td>14,000</td>
<td>16,000</td>
</tr>
<tr>
<td></td>
<td>Metropolitan Brush</td>
<td>150,000</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Provincial Brush</td>
<td>25,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Irish licence</td>
<td>2,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Isle of Man Licence</td>
<td>250</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Foreign Companies</td>
<td>62,505</td>
<td>64,000</td>
</tr>
<tr>
<td></td>
<td><strong>Total less expenses</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Brush accounts for 1882.

without putting down a trial installation. There were numerous published estimates of costs, but most of these were deficient (for example capital costs were forgotten) or biased. Some local authorities were content
with a report, but some, like the London authorities, the Commissioners of Sewers and the Metropolitan Board of Works, determined to see it in use.

Among provincial corporations, Liverpool showed the earliest interest. They installed trial lighting to explore the possibilities of the arc lamp as early as 1879. In late 1881 and early 1882 a large number of local authorities tried arc lighting, among them important boroughs like Birmingham, Blackburn and Leeds. These local authorities sometimes invited tenders for a temporary lighting installations and sometimes bought plant.

All these exhibitions and experiments greatly stimulated sales of arc lighting equipment. The amount of plant they required was large relative to the small output of equipment in 1881. In 1881 Brush sales were about £80,000. In 1882 they rose to £200,000. Calculations suggest that the concessionary companies may have spent as much as £100,000 on Brush plant in 1882 alone. Brush had to expand manufacturing facilities extensively and to meet the sharply rising demand they had to import some equipment from the American Brush Co.

There was naturally also an increase in demand for the arc lighting equipment of other firms. Sales of Siemens arc lighting equipment rose from £35,840 in 1881 to £83,780 in 1882. Crompton was clearly extremely busy although manufacturing facilities do not seem to have been expanded.

In 1832 incandescent lighting became known. In that year Crompton made the first large installation of incandescent lamps in England - at the Law Courts. The Edison lamp also made its appearance in England. An agreement was made with the Commissioners of Sewers in January 1832 to light Holborn Viaduct free for 3 months and subsequently at "gas price" if electricity could be supplied to private customers. In March 1832 an English Edison Company was formed to sell Edison incandescent lighting equipment in England.

Many of the arc lighting companies became interested in incandescent lighting. Siemens Bros. used Swan lamps in conjunction with their own arc lamps at Godalming in 1831. The British Electric Light Co. bought the Lane-Fox incandescent lamp patents. However it did not make much use of them and Lane-Fox repurchased them. He then sold them to Brush, but the latter at least up to 1883 - 4 showed only marginal interest in incandescent lighting. The Electric Light and Power Generator Co. purchased the incandescent lamp patents of Hiram S. Maxim in 1882. Crompton had been involved with both arc and incandescent lighting since 1830. Together arc and incandescent lighting could provide electric lighting of almost any intensity, and thus for any purpose.

In the first half of 1882, there was great enthusiasm over electric lighting, particularly arc lighting. There had been rapid and exciting technical developments, and many people felt they were at the dawn of the electrical age. At the time there was also a weak boom in other sections of the economy. The depression of the late seventies was very deep, and in the short revival of confidence from 1880 to 1882 the propensity to lend increased more rapidly than the propensity to borrow. Fairly considerable speculation in electric lighting was inevitable.

Many new companies were formed to exploit arc lamp patents. The Pilsen-Joel was forced to sell Pilsen arc lamps, and the Culcher Co. to sell Culcher lamps. The Electric Light and Power Generator Co. bought the arc lamp patents of Edward Weston, and changed its name to the Maxin-Weston Electrical Co. Only two companies however followed Brush in selling concessions, the Maxin-Weston Co. and the Pilsen-Joel Co. But they only sold one concession each.

There was considerable stock exchange speculation in Brush shares. In April 1882 Brush £10 paid ordinary shares stood at £23. Then they rose to a peak of £63 in May and thereafter fell again. But as late as September 1882 they were still as high as £24.

Table 4 shows it was easy to borrow money for electric lighting in the first half of 1882. It was particularly easy to borrow in May, when conditions on the stock exchange approached a "mania". Of the £3,053,575 borrowed by the issue of shares in 1882, £2,703,850 can be allocated to particular months. £1,924,000 was borrowed in the 2nd quarter, £1,530,000 in May alone.

Table 4.
Capital called up by companies formed in 1882 to exploit electrical invention.

| 1. Manufacturing companies or companies intending to manufacture | £ 737,000 |
| 2. Supply companies or companies intending to supply                | 1,150,000 |
| 3. Electrical Contractors                                          | 200,600  |
| 4. Companies formed to market miscellaneous electrical inventions (not always electric lighting) | 965,475  |
| 5. Companies intending to operate abroad                           | 646,500  |
|                                                               | 3,053,573 |

I have allocated companies into these groups on the basis of the name of the company. But this is not an infallible guide. Sometimes the name is misleading. Sometimes companies intended both to manufacture equipment and supply electricity. These companies have been put under manufacturers.

Source: Electrical Trades Directory. 1883.

There was thus a general feeling in 1882, particularly in the second quarter, that arc lighting would soon be used to a considerable extent, and that the widespread use of incandescent lighting would soon follow. In this situation people naturally thought of central station lighting. Whether there should be central station supply or not depended on whether there were sufficient economies of scale to justify it. It is possible to have electric lighting without central station supply.

1. The contemporary word central station has been used in this work rather than the modern word power station, in order to avoid confusion with the electricity stations specifically or mainly built to supply electricity for motive power.
but if there had been a considerable demand for electric lighting there almost certainly would have been sufficient economies of scale.

The arc lighting companies were very anxious to develop street lighting. In an already urban England, with streets lit by gas, there was a large market for street lighting. And lighting the streets was a good first step to general central station supply. Once wires had been laid it would not be difficult to give a supply to customers whose demand for light was too small for it to be worth while for them to have an isolated installation. Arc lighting by itself did not lend itself to extensive central station supply. In 1882 thirty two lamps were about the maximum which could be supplied by one dynamo, and most makers made dynamos for only 10 - 15 lamps. The small dynamos - they were not more than 30 KW at the outside - were best driven by portable or semi-portable engines. Distribution costs soon offset any advantage of grouping more than a small number of generators together. But incandescent lighting promised much greater economies of scale in generation. It was possible to increase the output of a constant voltage dynamo much more easily than it was to increase the output of an arc lighting dynamo. Edison saw this and in 1882 opened the large Pearl Street central station in the Wall Street area of New York City. For it he designed his famous Jumbo dynamos built to serve 1200 lamps (approximately 75 KW) and over four times the size of the largest incandescent lighting generators previously made.

In London the Edison installation on Holborn Viaduct was a central station, being to some extent a pilot scheme for Pearl Street. Edison sent over E.H. Johnson, one of his chief assistants, to begin the London Station.
When it opened in April 1832 it had 933 lamps connected to its mains. Arc lighting companies hoped to run both arc and incandescent lights from the same central station, although as the electrical circuits had at the time to be separate, the advantages of doing so were limited.

Before central station lighting could develop some permissive legislation was necessary. The crucial question was the opening of the streets to lay underground mains. Much of the early arc lighting simply used overhead wires, but it was clear that any substantial central station would involve underground mains. Who had the right to open up the streets was not at all clear. Even the local authorities were uncertain of their rights. Liverpool Corporation held that they had no powers to break up the streets of the city to lay electric lighting mains and sponsored a Bill in 1879 to give such powers. The 1879 Select Committee doubted this contention but reported that if local authorities did not have such powers under existing statutes (e.g. the Public Health Acts) ample powers should be given them. But the Committee felt that the time was not yet ripe to give general powers to companies to break the streets except by consent of the local authorities. By the first half of 1882 it was clear that some general permissive act was necessary, and one was introduced, covering any electricity supply undertaking laying cables under the street. General conditions were laid down. Intending suppliers could then apply to the Board of Trade either for a Provisional order or a Licence, a much cheaper procedure than a private Act of Parliament. A licence, which ran for seven years, required the consent of the local authority. However an

application for a Provisional Order would not be refused even if the local authority concerned opposed it, unless the Board of Trade was convinced that the local authority intended to start its own electricity supply. A very important provision under a Provisional Order was that the local authority should be able compulsorily to acquire an undertaking after 21 years from the granting of the Order at the then market value of the physical assets of the Company.

The boom was in essence a fairly large scale trial of an important innovation. There was only a small rise in the permanent demand for electric lighting. The result of the trial was that electric lighting was considered too expensive for widespread use. As a result the boom quickly broke, and having over stimulated productive capacity, all sections of the industry entered a long period of depression. It was real and not financial conditions which were responsible. The considerable stock exchange speculation of early May quickly disappeared, but Brush shares did not fall below the pre-bubble price. Enough had been borrowed in May to install a great deal of electric lighting, and the number of applications for provisional orders after August shows that confidence remained high. But the events of the 4th quarter of 1882 and 1883 showed that such confidence was excessive.

Central stations depended on a considerable use of electric lighting in a small geographical area. It was because events showed that the demand for electric lighting was small and that the attempt to begin them was doomed. But companies who expected extensive isolated lighting were equally disappointed.
Table 5.

Electricity supply. Provisional Orders and Licences granted by the Board of Trade, 1882 - 1912.

<table>
<thead>
<tr>
<th>Year</th>
<th>Provisional orders</th>
<th>Licences</th>
</tr>
</thead>
<tbody>
<tr>
<td>1882</td>
<td>69</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>2</td>
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<td>8</td>
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<td>5</td>
</tr>
<tr>
<td>9</td>
<td>75</td>
<td>4</td>
</tr>
<tr>
<td>1890</td>
<td>59</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>25</td>
<td>2</td>
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<tr>
<td>2</td>
<td>15</td>
<td>3</td>
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<td>23</td>
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<td>9</td>
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<td>1</td>
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<td>9</td>
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<tr>
<td>1910</td>
<td>25</td>
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</tr>
<tr>
<td>11</td>
<td>31</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>38</td>
<td></td>
</tr>
</tbody>
</table>

The number applied for was always greater. Some applications competed for the same area and some proposed schemes were unsound.

Source: B.P.P. Returns made annually by the Board of Trade.
Table 6.

Provisional Orders granted in 1882.

<table>
<thead>
<tr>
<th>Local Authorities</th>
<th>Companies</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>London</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Provinces</td>
<td>13</td>
<td>37</td>
</tr>
</tbody>
</table>

The Electric lighting Act received the Royal Assent in August 1882. The eagerness to begin a public supply of electricity can be gauged by the fact that one month later 83 applications had been made for Provisional Orders of which 55 had been granted by the Board of Trade.

The Brush concessionaries were well in the fore of the attempt to found central stations. Their applications for provisional orders were 48% of the total. Yet they all soon collapsed. The Brush Company of Scotland was the first to go but the Metropolitan Co. which had applied for as many as 26 provisional orders, followed it quickly. Before proceeding with its Provisional orders it decided to run a pilot scheme at Holborn. Estimates of cost and demand were made and it was thought that electricity would be supplied at "gas price" giving a return of 8½%. The stockholders however took a different view about the scheme and a committee of investigation set up by them reported that the demand estimates were excessive. Virtually only the shops would take the electric light and would use it only during business hours. Hammond (Chairman of the Hammond Electric Light and Power Co.) who was a large shareholder

endorsed the report but gave as a reason for the probable failure of the scheme that the scale of operation was too small. He offered to purchase the company so that a large scale station could be opened. But the shareholders, who were alarmed at the way the company was run, especially at the flotation of a subsidiary company, the City and Suburban Co., which they thought was a clear case of company mongering, were not impressed by Harmoni's offer and decided to cut their losses by voting the company into liquidation.

The Great Western Co. was more modest in its aims but no more successful. It had small establishments at Bristol and Cardiff comprising 62 arc lights and 398 incandescent lights in all and it also hire out portable and exhibition plant. Receipts were very small, 1882 - £520, 1883 - £1,433 and the loss for the latter year was £1,067 despite a drastic reduction of expenditure. In December 1884 the company was purchased by Anglo-American Brush. The experience of Brush Midland was much the same. They started with exhibition lighting in various parts of their territory - in Boston, Chester, Grimsby, Gainsborough and Reading, and had also some contracts to light various works where they aimed at a profit. After 18 months' operation their total losses amounted to £5,283. And there was little hope that business would, in the foreseeable future, improve. They did not go into Central Station work and the general trade depression kept down demand for isolated installations. An attempt was made to keep down expenses by pooling officials with the Great Western

Co. but when Anglo-American Brush offered to purchase the Company in December 1884 their offer was gladly accepted.

The South Eastern Brush Co. accomplished a little more. One technical problem that the Brush companies faced was that they wished to use incandescent as well as arc lighting and did not possess a complete incandescent system. They had bought the Lane-Fox patents which covered only the lamp, and the parent Brush Co. at the time had not a dynamo suitable for incandescent lighting. The Metropolitan Brush Co. tried, as they put it, "to adopt the Brush dynamo to low tension", but did not have the technical ability to succeed. The South Eastern Brush Co. tried to overcome this by developing a system of their own, in which accumulators were charged in series at a high voltage and discharged in parallel at a low voltage. This was an interesting system technically but was very expensive to perfect. Accumulators, a new invention, had to be developed and to do this S.E. Brush, joined by Provincial Brush, had to subsidise a company - the Consolidated Electric Co. - they had set up. This exhausted their cash reserves and when they finally opened a station at Colchester it ran for the first year at a loss, revenue covering only 32% of expenses. The Company was short of cash and was unable to raise any more. The shareholders wished to liquidate the company and in the

middle of 1885 the Station was closed down and the company wound up. The
Station had cost £7,338 to build, preliminary expenditure, on estimating
demand and obtaining Provisional orders, had been £3,981, and £7,000 had
been advanced to the Consolidated Co. This excludes the purchase money
for the Brush concession. The installation was sold for £345. The
Provincial Brush Co. had also been interested in the installation. They
had contributed £3,000 to the Consolidated Co. and intended to use the
accumulator system should it prove successful. They had also started
with small installations on which they had lost £6,824 in 15 months to
November 1883. Then they suspended many of their operations to wait for the
success of S.E. Brush. When the Colchester Station failed, Provincial
Brush also went into liquidation.

The most important Brush subsidiary was however the Hammond Co.
When it was liquidated in 1885 it did leave some legacy behind it. The
Company had first concentrated on selling and fitting "isolated" Brush
sets for factories - Robert Hammond claimed to have chosen the Brush light
because it was the most suitable for factories. In 1882 it made
installations of arc lights in the streets of several towns. The
operations of 1882 were successful and profits for Feb. - Dec. 1882 were
£8,086 after 12% depreciation of plant and £5,000 had been written off the
good will account. In addition £52,162 in shares of subsidiary companies

   1885.
Hammond had "sub-sold" its concessions for some areas) were placed to reserve. The Hammond Co. solved the problem caused by the lack of a Brush incandescent lighting dynamo by obtaining the rights of a new constant voltage dynamo. In 1882 S.J. de Ferranti started manufacturing alternators of a new and extremely good design, and Hammond, first appointed sales agent for the company of Ferranti, Thomson and Ince, effected the amalgamation of this Company with his own firm in 1883.

A provisional order for Hampstead obtained by Ferranti, Thomson and Ince was taken over and plans were laid to build a central station there. But by this time it was found to be impossible to raise capital. Meanwhile in 1882, following the success of Hammond's demonstrations of Brush arc lighting at Brighton, Hastings and Eastbourne, subsidiary companies had been set up in the latter two places. In the boom they found it easy to raise £5,000 each in cash for permanent working. After the boom had collapsed, they had to rely on the parent company for cash, but enough was forthcoming to establish there on a small but lasting basis. For the year ending 31 December 1883 the Hammond Co. showed a net loss of £29,180, but by the time of its liquidation the Brighton, Hastings and Eastbourne installations were sufficiently firmly established to continue on their own.

The experience of other companies was similar to that of the Brush concessionaries. The Pilsen-Joe Co. which had applied for

Table 7.

<table>
<thead>
<tr>
<th>Year</th>
<th>Hastings arc</th>
<th>Hastings incandescent</th>
<th>Brighton arc</th>
<th>Brighton incandescent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1882</td>
<td>16</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1883</td>
<td>40</td>
<td></td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>1884</td>
<td>27</td>
<td>96</td>
<td>34</td>
<td>516</td>
</tr>
<tr>
<td>1885</td>
<td>29</td>
<td>456</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>1886</td>
<td>27</td>
<td>576</td>
<td>27</td>
<td>875</td>
</tr>
</tbody>
</table>

Sources: Reports of Brighton, Hastings and Eastbourne Electric Supply Cos. and R.H. Parsons, op. cit.

3 provisional orders in 1882, combined, like many of the companies, supply and manufacturing. But it became by the late eighties chiefly concerned with supply, lighting small groups of buildings. The installations were scarcely profitable. Up to 1885 - 6 losses were heavy. In the two following years small profits were made and at the end of 1888 - 9 it was just breaking even over its installations. An adverse report by a committee of shareholders sent the company into liquidation in December 1889.

Another company doing some supply work, the Maxim-Weston Co. did very little business and went into liquidation in 1883.

The Edison and Swan Companies applied for 5 provisional orders between them in 1882, and started a number of small installations where

1. Pilsen-Joal meetings. various years.
2. Maxim-Weston meetings. various years.
light was sold for a fixed payment p.a., as well as the "acton" station on Holborn viaduct. In 1833 the two companies amalgamated and by this time it was clear that these early installations were not profitable. This would not have been very important if the unprofitability had been purely because of their small size and if they had served as good advertisements for the starting of large profitable Central Stations. But by then it was clear that the expected large demand was not going to be realised. Borrowing had become difficult because of the reaction of lenders to the speculation of 1832 and to the Electric Lighting Act. Although, because of this the Edison-Swan Co. did not want to undertake general supply, it was still prepared to pioneer one big installation which could serve as the basis for a central station. The installation in question was at Victoria Station.

Meanwhile the installations continued to lose money and were largely responsible for the big loss of June 1833 - June 1834. Revenue from then in that year was £9,447 about 1/3 the company's total revenue. Accordingly these installations were carefully sifted and 4 out of 9 were closed. It was resolved to undertake no more of this unprofitable business. The Holborn Station was being worked at a serious annual loss but nevertheless was kept open for the time being. But the policy of closing rented installations continued, 2 more contracts were terminated in the financial year June 1834 - June 1835 and early in 1836 the

Holborn Station was closed. Notice was given that supply from the remaining installations was to be terminated in September 1886. Thus only the Victoria Station installation remained. The lighting of Victoria Station had been completed by the end of 1884 at a cost of £16,000 – £17,000, but the original intention to extend it into a central station was abandoned and the installation was not profitable. This was the only result of a large expenditure on lighting installations which by November 1884 stood at £77,251.

Thus the attempt to begin large scale electricity supply for lighting failed. Some electric lighting remained and from 1883 onwards the amount of plant sold for electric lighting rose fairly steadily. Until the late eighties it was all for isolated installations. Arc lighting was used in factories, docks, railway stations, etc; incandescent lighting in large private houses, clubs and ships. Ships were important, for the advantage of electricity over oil was considerable.

3. Meeting of Edison-Swan November 1884. Elect. Vol. 14 P 19. 15 November 1884. This was a substantial sum, easily enough to establish a central station. By the end of 1885 out of the 37 central stations outside London which had been running for at least two years, 31 had spent less than £77,000 on capital account.
and gas was impracticable. In 1883 for example the Edison-Swan Company supplied equipment for 32 ships and 23 land installations.

The principal reason for the failure of electric lighting to be used much in the eighties was its cost relative to that of gas lighting. The pioneers had thought that electric lighting would only find a market if it could be supplied at the gas price. Yet it was impossible to do this profitably.

As was seen earlier in this chapter, arc lighting costs cannot be compared with the costs of gas lighting without considering the lighting purpose. In factories arc lighting was sometimes cheaper. This was partly because of the need for good illumination and partly because arc lighting costs were often particularly low in factories. Some had spare engine power and dynamos could be connected to existing engines and run for very little extra cost. Ordinary employees of the factory could periodically change the carbons with the loss of very little time. This sometimes meant that direct costs could be reduced to carbon costs alone. Night shift working kept capital costs low. On the other hand while it is difficult with very scanty evidence to come to a balanced judgment on the matter it is likely that for the vast majority of factories arc lighting was more expensive than gas lighting at least up to 1900. But where little light was required, as in the streets, the arc lamp was nearly always more expensive than gas lighting. Naturally it gave more light but this was often not wanted at the extra cost. Where improved street lighting was required
it could be more cheaply done with better gas burners. One can quote several examples of the high cost of arc lighting compared with gas.

In 1831 60 Brockie lamps replaced 245 gas jets in Liverpool. But the running costs alone, without allowance for interest or depreciation, were £2,600 per annum while the old gas lighting cost only £1,283. Aberdeen experimented with a Brush 16 arc system in 1833. The lights cost £222 9s. 6d. p.a. for running expenses alone. Gas had previously been used at an annual cost of £65 10s. Table 8 shows how much more expensive than gas was the experimental arc lighting in the City of London in 1831. As both Siemens and Brush were working below costs the Table understates the difference.

These costs refer to the early eighties. Costs fell rapidly afterwards. But it was not until the late nineties that arc lighting was much used in the streets. Even at the end of 1890 there were only 700 arc lamps in the streets of English towns. Then electricity for street lamps cost about 2d per KWh while in the early eighties it cost about 9 - 10d. Carbon costs also fell dramatically over this period.

1. Better lighting was being installed at the time. The Siemens regeneration burners on Holborn Viaduct cost 3 - 8 times the amount of the old gas lighting. The very bad lighting in Waterloo Place London was replaced by improved gas lighting costing 11.5 times as much. But this demand was limited.


Table 8.

Cost of gas and arc lighting in the City of London 1881.

<table>
<thead>
<tr>
<th>District</th>
<th>System</th>
<th>Cost of working for 12 months</th>
<th>Cost of fixing &amp; removing</th>
<th>Total cost</th>
<th>Cost of gas lighting hither proposed to be replaced</th>
<th>No. of gas lamps to be replaced</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Brush</td>
<td>£660</td>
<td>£750</td>
<td>£1,410</td>
<td>32</td>
<td>150</td>
</tr>
<tr>
<td></td>
<td>Crompton</td>
<td>£2,007</td>
<td>£500</td>
<td>£2,507</td>
<td>17</td>
<td>152</td>
</tr>
<tr>
<td></td>
<td>Siemens</td>
<td>£2,050</td>
<td>£1,650</td>
<td>£3,700</td>
<td>29</td>
<td>144</td>
</tr>
<tr>
<td></td>
<td>Jablochkoff</td>
<td>£1,500</td>
<td>£1,550</td>
<td>£3,050</td>
<td>48</td>
<td>144</td>
</tr>
<tr>
<td>2.</td>
<td>Crompton</td>
<td>£2,167</td>
<td>£560</td>
<td>£2,727</td>
<td>16</td>
<td>176</td>
</tr>
<tr>
<td></td>
<td>Jablochkoff</td>
<td>£1,580</td>
<td>£1,350</td>
<td>£2,930</td>
<td>?</td>
<td>161</td>
</tr>
<tr>
<td></td>
<td>Siemens</td>
<td>£1,850</td>
<td>£980</td>
<td>£2,830</td>
<td>31</td>
<td>164</td>
</tr>
<tr>
<td>3.</td>
<td>Crompton</td>
<td>£2,475</td>
<td>£650</td>
<td>£3,125</td>
<td>18</td>
<td>132</td>
</tr>
<tr>
<td></td>
<td>Siemens</td>
<td>£2,270</td>
<td>£1,455</td>
<td>£3,725</td>
<td>32</td>
<td>138</td>
</tr>
</tbody>
</table>

Sources: Engineering Nov. 19, 1880 and Electrician 27 May 1882.

In 1880 carbons cost about 9d. per foot. By 1894 they cost slightly over 1d. Thus very substantial cost reductions were necessary before it became economical to use arc lighting in the streets.

1. In 1893 Professor L.B. Marks invented the enclosed arc lamp. This reduced carbon consumption to between a fifth and a quarter of that of the open arc. But the efficiency of the lamp was less that that of the open arc lamp and it used 60% more current. At English price ratios it would only have been worth adopting the enclosed arc if the cost of changing carbons was very substantially reduced.
Because incandescent lamps were of the same power as gas burners the costs of gas and electric incandescent lighting can be simply compared. This can be done from Table 9 once the costs of gas and electricity are known.

Table 9.
Costs per hour of 16 c.p. gas and electric lamps. pence.

1. Gas.

<table>
<thead>
<tr>
<th>Gas prices per 1000 cu.ft.</th>
<th>2/6</th>
<th>3/-</th>
<th>3/6</th>
<th>4/-</th>
<th>4/6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consumption of gas, in cu. ft. per hour</td>
<td>5</td>
<td>0.15</td>
<td>0.18</td>
<td>0.21</td>
<td>0.24</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>0.18</td>
<td>0.22</td>
<td>0.25</td>
<td>0.28</td>
</tr>
</tbody>
</table>

2. Incandescent electric.

<table>
<thead>
<tr>
<th>Electricity prices per KWh pence.</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency of lamps in watts per c.p.</td>
<td>4.0</td>
<td>0.26</td>
<td>0.32</td>
<td>0.38</td>
<td>0.45</td>
<td>0.51</td>
<td>0.65</td>
</tr>
<tr>
<td></td>
<td>3.5</td>
<td>0.22</td>
<td>0.28</td>
<td>0.34</td>
<td>0.39</td>
<td>0.45</td>
<td>0.50</td>
</tr>
<tr>
<td></td>
<td>3.0</td>
<td>0.19</td>
<td>0.24</td>
<td>0.29</td>
<td>0.34</td>
<td>0.38</td>
<td>0.43</td>
</tr>
<tr>
<td></td>
<td>2.5</td>
<td>0.16</td>
<td>0.20</td>
<td>0.24</td>
<td>0.28</td>
<td>0.32</td>
<td>0.36</td>
</tr>
</tbody>
</table>

There are no overall statistics of gas prices before 1837. But in 1831 gas cost about 3/- per cu. ft. in London, about 2/6 in the big northern towns (Manchester, Leeds, Liverpool, Birmingham and Sheffield) and about 3/6 to 4/- in the country as a whole. 16 candle power gas lamps used 5 - 6 cu. ft. per hour.
Table 10.

Gas prices. All undertakings.

<table>
<thead>
<tr>
<th>Year</th>
<th>Average Revenue (Shillings per 1000 cu. ft.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1837</td>
<td>3.58</td>
</tr>
<tr>
<td>1890</td>
<td>3.66</td>
</tr>
<tr>
<td>1895</td>
<td>3.49</td>
</tr>
<tr>
<td>1900</td>
<td>3.81</td>
</tr>
<tr>
<td>1905</td>
<td>3.38</td>
</tr>
<tr>
<td>1910</td>
<td>3.42</td>
</tr>
</tbody>
</table>

Source: Annual returns of the Gas Undertakings. B.P.P.

Electric incandescent lamps used about 4.5 watts per c.p. in 1880. Efficiencies then rose to about 3.5 w. per c.p. by the end of the eighties. Although some manufacturers sold lamps of efficiencies up to 2.5 w. per c.p. the principal ones did not and efficiencies did not further improve until the introduction of metal filament lamps in the years 1908 - 10. However by then the incandescent gas mantle was widely used and thus there is no point in comparing metal-filament lamps with simple gas burners.

In 1882 electricity cost at least 9 - 10d. per KWh. Evidence is rather scanty. In 1884 the Brighton Company charged 1/2d. per KWh. S.R. Brush charged 6d. but only covered 30% of expenses. In 1883 the Cadogan Electric Supply company and the Chelsea Company charged 7d. and 8d.
In the early nineties more is known as there were more electricity supply companies. In January 1893 the unweighted average price charged by 35 undertakings was 7.2d and in January 1896, 6.9d for 54 undertakings.

However in the early eighties electricity generated in isolated installations was often cheaper than central station supply. This was because there were few economies of scale in generation to set off against the cost of primary mains. The distribution network could easily account for half the initial costs of a central station supply system. In 1882 Brush dynamos operating at the usual lighting load factor were generating electricity at 8 - 8.5d per KWh. Some engineers claimed in some installations to be able to supply electricity for less than this.

Sir John Coope, owner of Beerchurch Hall, where Crompton installed electric lighting in 1883 estimated that electricity cost as little as 3.5d per KWh. This sounds very optimistic.

In most cases in 1882, electric incandescent lighting cost three times as much as gas. By the end of the eighties improvements in the efficiency of lamps and reductions in the cost of current brought incandescent lighting down to about twice the gas price. By the late nineties the average revenue of a random sample of twenty central stations selling electricity solely for lighting was 4.7d per KWh. At that price there was very little difference between the cost of gas and electric lighting.

1. In 1898.
The superior quality of electric lighting would lead some people to adopt it even though it was more expensive than gas lighting. When it cost about twice as much as gas lighting quite a number of people were willing to use it, as the monopolistic control of electricity supply at the end of the eighties, and the late nineties shows. But at three times the gas price demand seems to have been very small. It can be argued that the electricity entrepreneurs of the early eighties made a bad mistake when they tried to sell electricity at the gas price. Sir William Siemens was a lone voice insisting in 1882 that electric incandescent lighting was the "light of luxury". Others were determined to market electric lighting on the grounds that it was as cheap, or cheaper than gas. The long controversy in the technical press on the relative cheapness of gas or electric lighting bears testimony to this. The result was that electricity was fixed at a price to make electric lighting as cheap as gas lighting. Gas was cheap in England, and the losses of lighting installations recorded earlier in this chapter show the inevitable outcome.

Writing about Edison, H.C. Passer points out that it was sound entrepreneurial policy for Edison to charge the "gas" price in New York City. But it was unsound for the Edison Company to do the same on Holborn Viaduct. The gas industry in the United States was inefficient and profiteering; in England it was reasonably efficient and municipalisation had eliminated monopoly profits.

1. H.C. Passer, op.cit. Chapters 7 and 8.
2. This question is discussed in detail in the appendix to this chapter.
If intending suppliers in England had adopted a different pricing policy they might have had a modest success. But it would have been modest, certainly not enough to justify the expectations of 1882.

The timing of the building cycle must have retarded the development of electric lighting in England. In new houses, occupiers decided between gas and electric lighting by comparing the average costs of both and weighing the difference against differences in utility. But in existing houses already accustomed for gas the consumer had also to take into account the cost of wiring, which was to be added to electric lighting costs. Also even if rationally justified, wiring for electricity would tend to be delayed because it could be a large initial expense. Building boomed in Britain during the 1870s and a very large number of new houses were built. Consequently throughout the eighties and extending into the first half of the nineties there was a low demand for new houses.

Where electric lighting might have been adopted by firms and not final consumers, the timing of the general trade cycle must have hindered its adoption in the eighties. After a strong boom in the seventies, the economy was depressed through most of the eighties. The boom of 1891 - 2 was only a small one, and recession followed before full capacity was reached in all industries. One retarding factor I have avoided discussing so far, although it was thought by contemporaries to have been important. This was the effect of the compulsory purchase clause of the 1832 Act on the supply of capital.

In 1884 the Statist declared that "the electrical infant was strangled at birth by the Electric Lighting Act." In 1886 three ascending

Bills were presented to Parliament, and the House of Lords appointed a committee to hear evidence for and against them and it also reviewed the effect of the Act of 1882. Before this committee the representatives of the electrical industry, Crompton and J.S. Forbes, the Chairman of Edison-Swan, argued that they were ready for central station supply in 1882, but having started on it were unable to complete their plans because the Electric Light Act made finance impossible to obtain. In this they were supported by evidence from Louis Cohen at one time a stockbroker who said that the Act was "almost prohibitory to the finding of capital" and J.M. MacDonald, a partner in the firm of Messrs. Matheson and Co., of Lombard Street, who said, more moderately, that the purchase clauses "deterred investors". There is no doubt that this was so; even Sir G. Morrison, the Town Clerk of Leeds admitted that "after the very strong evidence which has been given by some gentleman that it is so, I do not like to say that the Act may not have had some remote connection with it" (the failure of the supply companies), but he went on to question the importance of this explanation. Certainly the emphasis placed on the deterrent effect of legislation by J.S. Forbes before the committee is not the same as the emphasis placed on the unprofitability of electric lighting in his speeches to the shareholders of Edison-Swan. The representatives of the municipalities, who appeared before the committee

2. ibid., Qs 1888 - 9.
3. ibid., Q 1652.
to oppose the repeal of the purchase clause - although they agreed the
years of operation allowed to the companies might be increased - placed
great emphasis on the high cost of electric lighting, "My own view and the
view of many of those connected with corporations with whom I have
conversed is that the real cause of the failure of the electric lighting
companies has been the impossibility at present from a commercial point of
view, for them to compete successfully with gas as an illuminant" continued
the Town Clerk of Leeds. The municipalities of Liverpool, Birmingham,
Blackburn and Leeds supported their contentions with accounts of their own
experience of the costs of electric lighting in 1882.

Most of the evidence supports the contentions of the municipalities.
Quite enough capital was raised in 1882 to have supplied the small demand
for electric lighting if it had been properly used. After the initial
mistakes it is arguable that if more capital could have been raised it
would have been possible for intending suppliers to carry on at higher prices
until they established themselves. However, after all the protestations of
electric lighting advocates as to its cheapness it is not clear that higher
prices would have led to higher profits. Raising prices, would probably
have driven away customers, even those who would have used electric light
if they had been charged the cost price in the beginning. Higher prices
were not generally tried; the Edison station at Holborn for example was
closed before there was any resort to higher charges.

1. Ibid., Q 1652.
It was not only the Act that made funds difficult to get. Many ordinary shares were speculative in the eighties; they could only be sold in times of boom. Electric lighting shares were more speculative than most. The collapse of the boom was quite sufficient to make the further sale of shares extremely difficult.

The industry found in legislation a convenient scapegoat for its allegedly poor performance. It is a scapegoat which appeared again and again. But perhaps the best way to sum up the experience of the eighties is to quote the considered opinion of Alexander Siemens in his Presidential address to the Institution of Electrical Engineers in 1894:

"However much other causes may have contributed to delay the development of electrical engineering (he had talked of legislation), it is clear that the principle one must be looked for in the exaggerated expectations that were raised, either by ignorance or design, when the general public first seriously thought of regarding electricity as a commodity for everyday use .... There was a short time of excitement to the public and of profit to the promoters; then the confidence of the public in electricity was almost destroyed and could only be regained by years of patient work".


Appendix.

The relative costs of gas and electric lighting in the United States and Britain.

In the United States the experiments with electric lighting were successful, and for the rest of the decade the adoption of electric lighting proceeded rapidly. The question arises as to whether this was due to the high cost of electric lighting in this country. The data in this appendix tends to show that the difference in the two countries was due rather to the high cost of gas in the United States and reinforcing this, the high rate of urban expansion.

Relative prices of gas and electricity have been calculated, and so have the prices of some of their factor inputs. From prices per physical unit in £ and $ an exchange rate in $ per £ has been computed for each commodity. To see what was relatively expensive and relatively cheap in both countries these exchange rates averaged over several years (usually 5), have been expressed as a percentage of the gold standard exchange rate = $ 4.85 = £1. High figures suggest high relative U.S. prices.

1. Gas prices.

<table>
<thead>
<tr>
<th>Year</th>
<th>Big towns</th>
<th>All towns</th>
</tr>
</thead>
<tbody>
<tr>
<td>1878</td>
<td>316</td>
<td></td>
</tr>
<tr>
<td>1881</td>
<td>318</td>
<td>263</td>
</tr>
<tr>
<td>1888 - 9</td>
<td>224</td>
<td></td>
</tr>
<tr>
<td>1889 - 90</td>
<td></td>
<td>159</td>
</tr>
</tbody>
</table>

The 1881 U.S. figure has been estimated by interpolating between 1878 and 1888 prices. A constant rate of fall has been assured.


Britain. B.P.P. Return of Metropolitan and other gas companies.

2. Electricity prices

London and New York average revenue per unit.

1895 - 8 115.

For New York the figures are those of the Edison

For London an average of 6 undertakings.

There are no satisfactory earlier figures.

Below are given the principal inputs of gas and electricity undertakings.

Costs as % of total costs.

<table>
<thead>
<tr>
<th></th>
<th>Average of 3 London Gas Cos. 1891</th>
<th>Average of 6 London Electricity Cos. for 1891 and 7 for 1894</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>47</td>
<td>22</td>
</tr>
<tr>
<td>Labour</td>
<td>13</td>
<td>14</td>
</tr>
<tr>
<td>Capital</td>
<td>20</td>
<td>28</td>
</tr>
</tbody>
</table>

Capital costs were calculated at 15% on the capital stock used for output.

The calculation of the latter was difficult as gas companies figures included expenditure on superseded works and electricity companies were working below full capacity.
The result is crude but unlikely to be far enough out to affect the conclusions. It may be argued that capital costs for gas should be less than 15%, as the rate of depreciation was lower than for electricity. But a lower rate would strengthen my argument.

Below are the relative costs of some of the inputs of gas and electricity.

<table>
<thead>
<tr>
<th>Coal (export value)</th>
<th>Pig Iron</th>
<th>Copper</th>
</tr>
</thead>
<tbody>
<tr>
<td>U.S. average of No. 1 Foundry</td>
<td>U.S. smelter fob works average value</td>
<td>U.K. average value of exports and imports of unwrought copper.</td>
</tr>
<tr>
<td>Gray forge (after 1831)</td>
<td>156</td>
<td>171</td>
</tr>
<tr>
<td>Gray lake forge, Bessemer (after 1885)</td>
<td>134</td>
<td>146</td>
</tr>
<tr>
<td>U.K. average of Cleveland, Cumberland, North and South Staffs, and Scots pig.</td>
<td>110</td>
<td>117</td>
</tr>
<tr>
<td></td>
<td>95</td>
<td>103</td>
</tr>
</tbody>
</table>

**By-products of gas works.**

<table>
<thead>
<tr>
<th>Coke</th>
<th>Tar</th>
</tr>
</thead>
<tbody>
<tr>
<td>U.S. average value fob oven</td>
<td>U.K. average value of imports</td>
</tr>
<tr>
<td>U.S. average values of exports of coke and cinders</td>
<td>U.S. domestic price</td>
</tr>
<tr>
<td>1880-4</td>
<td>1885-9</td>
</tr>
<tr>
<td>56</td>
<td>53</td>
</tr>
<tr>
<td>42</td>
<td>31</td>
</tr>
</tbody>
</table>
Note:

Prices vary quite considerably in different locations. For example in the U.K. in 1890 coal at the pit head had an average value of 8.25 shillings per ton, while the declared value of exports was 12.39 shillings per ton and the London price (at the Royal Greenwich hospital) was 18.42 shillings per ton. This is owing to quality as well as location. Care has been taken to make the price time series used in compiling the above table as comparable as possible, but the results are approximately rather than exactly correct. One source of error should be noted; for copper, coke and tar English export values are used and compared with internal U.S. figures. In general this will overestimate the internal English value and make the figures in the table a little too low.

Sources: U.S. Historical Statistics
Statistical abstract 1903.
Bulletin of the department of Labour No. 39.

U.K. Board of Trade Report on Retail and Wholesale prices 1902
Parliamentary Papers, Annual Abstract of Trade.

Costs of coal and capital were significantly different percentages of costs of gas and electricity (at the 1% level).

These are clearly the categories to investigate to see whether relative prices were different in the two countries. Unfortunately there is insufficient information about capital costs. All we can do is to note the interesting but inconclusive point that iron, which was used much more extensively in gas works than in electricity stations was relatively expensive in the United States in the 1830s. On the coal side the picture is much clearer. Coal was relatively expensive in the United States in the 1830s. Also in the eighties and nineties by-products of gas works were much more valuable in Britain. Coke and tar accounted for about 75% of the value of these by-products. The sales of residuals in England were a high proportion of the value of coal used - 56.5% in 1878 and 72% in 1889.
The difference of coal and by-product prices could substantially affect the price of gas in the two countries, as can be shown by the following arithmetic. Let us assume fixed physical inputs and an appropriate exchange rate so that the same monetary unit can be used in both countries. Let the cost of gas and residuals in England equal 100 units of money. Coal costs are then about 45 and other costs 55. If residual sales amount to 60% of coal cost, total costs net of residual are 45 - (60% of 45) + 55 = 122.

If in the United States coal costs 50% more than in England, but the price of all other factors is the same, gas plus residuals costs (150% of 45) + 55 = 122.

Rendered prices are half that in England so the net cost of gas is 67 - (30% of 45) + 55 = 103.

\[ \frac{103}{73} = 1.43 \]

This calculation ignores much but it does give some indication of the effect of full and by-product prices.

Thus while factor prices explain some of the difference between American and British gas prices a large gap is left. The main explanation for the remaining difference is the difference between the wasteful monopolistic American gas industry and the controlled and partly municipalised English industry.

The British gas industry was controlled by maximum prices, dividend limitation (the two were often combined by a sliding scale which permitted higher dividends if prices were lowered) and devices to make the
watering of capital difficult. Such control, however, was not sufficient to prevent all abuse of the monopoly position.

As a result the municipalities had begun purchasing gas works in the 1870s and running them more efficiently. When this happened prices were usually reduced, and the quality of management usually rose. "Gas and Water" a London technical journal, says that in almost every instance where corporations took possession of the works the price of gas was lowered. The "Times" commenting on this stated "In all the boroughs to which reference has been made, a spirit - an intelligent spirit - of progress is to be found actuating the corporations."

As early as 1831 the municipalities had a 29% share of the total sales of gas. Moreover it was the big towns which took the lead. Gas was thus often municipalized and cheap where electricity was most likely to be used for lighting.

In the United States the complaints about the gas companies were often prefixed with a rhetorical question asking why gas should be very much more expensive than in England. The companies were said to be technologically backward, wasteful and unconcerned with the value of by-products. James quotes the address of the President of the American Gas Association to the Association in 1833 in which he estimated that gas would be supplied in New York - by efficient works - at 65 $ per 1,000 cubic feet. In 1878 gas

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1. See J.A. Cushing, "A Further plea to Congress with prayer for such investigation into the affairs of the Washington Gas Light Company as will lead to an equitable adjustment of price, quality and measurement of gas and a proper protection of consumers. Washington D.C. 1871.

cost £2.25 per 1,000 cubic feet, and £1.25 in 1833. This may be optimistic but the city works at Wheeling, West Virginia charged only 90.6 per 1,000 cubic feet while some companies charged as much as £5.00. The waste of gas was high, being 25% in New York against 9.5 in England. The Northern Liberties Company in Philadelphia allowed valuable ammoniacal liquor to run to waste and the Philadelphia Gas Trust did little better. Periodic competition seems to have had the long run result of increasing the price as price wars were followed by agreements, and the only lasting result of the period of competition was much overinvestment in plant, particularly distribution mains. Watering of capital seems to have been far greater than in England. The New York companies capitalized at £26 million; when they amalgamated they raised their capital stock to £47 million. Capitalization varied from between £6.25 to £15.00 per 1,000 cubic feet sold, whilst eminent gas engineers suggest that £2.50 to £5.00 was sufficient. In London, capital was £2.77 per 1,000 cubic feet sold. Some cities had started to run their own gas works and had reduced prices substantially but these were very much smaller proportion than in England.

The behaviour of gas prices in the two countries in the 1830s confirms firstly that American gas companies exploited their monopoly position by short run profit maximisation, and secondly that the relatively high costs of electric lighting in England resulted in a relatively much lower cross elasticity of demand between gas and electric lighting.

Gas prices fell much more in the United States, much more than could be accounted for by the factor fall of coal prices. Traditional monopoly analysis suggests that profit maximisers will reduce prices sharply

1. These examples come from E.J. James, op.cit.
when demand becomes more elastic. The introduction of electric lighting in the United States at the gas price increased the elasticity of demand for gas at the relevant price range very considerably. It could not have done so in England. Hence we would expect a much bigger price reduction in the U.S. This is what happened.

<table>
<thead>
<tr>
<th>U.S. gas prices</th>
<th>Gas price 1873 = 100</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>6 big towns</strong></td>
<td>1873: - 100</td>
</tr>
<tr>
<td><strong>All towns</strong></td>
<td>1873: - 100</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>England &amp; Wales</th>
<th>England &amp; Wales</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>London</strong></td>
<td>(1873 = 100)</td>
</tr>
<tr>
<td>1873: - 100</td>
<td>1891: 69</td>
</tr>
<tr>
<td>1890: 45</td>
<td></td>
</tr>
<tr>
<td><strong>All companies</strong></td>
<td>(1891 = 100)</td>
</tr>
<tr>
<td>(Sample) 1891: 100</td>
<td>1899: 92</td>
</tr>
<tr>
<td>1899: 92</td>
<td></td>
</tr>
</tbody>
</table>

| London and 5 major cities (1891 = 100) | 1891: 100 | 1899: 85 |

U.K. Returns of the Gas Companies and the Board of Trade Parliamentary papers.
The market for central station lighting (supplied by electricity of gas) grew at a much faster rate in the United States than in Great Britain. It is possible to measure light consumption, albeit crudely, and the results are below, in millions of 16 candle power light hours.

<table>
<thead>
<tr>
<th>Year</th>
<th>United States</th>
<th>England &amp; Wales</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Supplied by gas lighting</td>
<td>Supplied by electric lighting</td>
<td>Total</td>
</tr>
<tr>
<td></td>
<td>Supplied by gas lighting</td>
<td>Supplied by electric lighting</td>
<td>Total</td>
</tr>
<tr>
<td>1869</td>
<td>1840</td>
<td>nil</td>
<td>1840</td>
</tr>
<tr>
<td>1882</td>
<td>13,320</td>
<td>negligible</td>
<td>28,084</td>
</tr>
<tr>
<td>1890</td>
<td>8,880</td>
<td>4,240</td>
<td>13,120</td>
</tr>
<tr>
<td>1891</td>
<td>8,880</td>
<td>4,240</td>
<td>13,120</td>
</tr>
<tr>
<td>1899</td>
<td>13,320</td>
<td>negligible</td>
<td>20,040</td>
</tr>
<tr>
<td>1900</td>
<td>10,050</td>
<td>14,500</td>
<td>24,550</td>
</tr>
</tbody>
</table>

This partly accounted for by the faster urban growth rate in the U.S. (measured by the growth in the population in towns of more than 25,000 people, as can be seen in the following figures.

<table>
<thead>
<tr>
<th>(1)</th>
<th>Central station light growth rate per annum</th>
<th>(2)</th>
<th>Urban population growth rate per annum</th>
<th>(1) - (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>5.30%</td>
</tr>
<tr>
<td>1869-1899-90</td>
<td>9.8</td>
<td>4.5</td>
<td>5.30%</td>
<td></td>
</tr>
<tr>
<td>England &amp; Wales</td>
<td>(1881-1882)-(1890-1)</td>
<td>4.6</td>
<td>2.1</td>
<td>2.59%</td>
</tr>
<tr>
<td>United States</td>
<td>1890-1900-90</td>
<td>7.2</td>
<td>3.6</td>
<td>3.65%</td>
</tr>
<tr>
<td>U.K.</td>
<td>(1890-1900-1)</td>
<td>4.8</td>
<td>2.2</td>
<td>2.80%</td>
</tr>
</tbody>
</table>

1. First sales of gas and electricity were taken. U.S. gas sales are given in H.C. Passer op.cit. P 202 & 199. U.S. electricity sales.
Two conclusions emerge. One is that electricity was at a relative disadvantage in Britain where it had to replace gas, while in the United States there was so little central station lighting in 1880 that it was a question of new consumers choosing gas or electricity. Secondly the continued growth of gas sales in Britain, while almost the whole growth segment in the United States was filled by electricity sales, confirms the relative high cost of electric lighting in Britain.

are (a) for 1890 based on the number of arc and incandescent lamps in operation (Passer op.cit. PP 70 & 206). It was assumed arc lamps were used 5½ hours per night. For incandescent lamps the London number of lamps: KWh assumed ratio for 1891 was used (34.7 KWh p.a. 90% confidence interval 28.4 - 41.0). Central station supply is estimated to be 80% of this figure (b) 1899. 1902 figure given in J.K. Gould. Output and productivity in the Electric and Gas Utilities 1899 - 1912 N.B.E.R. 1946. 1899 figures estimated by assuming a constant rate of growth between 1890 and 1902.

British sales of gas are given in the Board of Trade Returns (B.P.P. various years.) No allowance has been made for the use of gas for other than lighting purposes.

Electricity sales in 1891 are those of the London Companies. Other sales were very small indeed. For 1900 the figure is taken from Table 22. To convert to a light hour basis I have assumed a 16 c.p. lamp hour took 5 c.ft. gas, 64 watts in 1889 - 1, and 60 watts in 1899 - 1900.
Chapter 2.

The Genesis of Public Supply.

The boom of 1882 was primarily an unsuccessful trial and the public supply of electricity dates from the early 1890s. The first power stations were established in London in the years 1889 - 92, and in the early and middle 1890s electricity supply spread to the provinces. However aggregate capital expenditure on power stations was at first fairly small; the peak period in power station construction before 1914 came in the years 1893 - 1904.

There are several reasons why electric supply started in London. The London undertakings were private companies, while many of the big provincial stations were owned by the municipalities, who were anxious to avoid too speculative ventures and wanted to see what would happen in London. Also the pioneers were anxious to start electric supply in an area where it would be most noticed. But perhaps most important is the nature of the market. Electricity supply was for electric lighting. Electric trams were starting in the U.S. in the late 1880s but were scarcely thought of at the time in England, and electric power was understood to be a development of the future. Electric lighting in this country was something for the wealthy individual rather than for businesses. For, by the middle eighties, most people had come round to Sir William Siemens's view that electric lighting was the "light of luxury". London provided a high income market sufficiently closely grouped spatially.

1. For detailed engineering histories of the early London Companies see R.H. Parsons, op.cit., Chapter 5.
for the power stations serving a small area to be profitable while charging high prices for energy, which made electric lighting 2 to 3 times as expensive as gas lighting. The West End of London by the middle of the eighties boasted many "isolated" installations, not only in theatres and clubs but in large private houses. In some cases the wealthy gentlemen of, for example, Grosvenor Square clubbed together to provide plant to light several houses. Several of the early supply undertakings in fact grew out of such "isolated" installations. In 1883 Sir Coutts Lindsay installed electric lighting in the Grosvenor Gallery, a picture gallery in Bond Street, and the demand for light from neighbouring residents and shopkeepers led him to begin a larger and more permanent installation in the Gallery in December 1884. Its success led in 1887 to the formation of the London Electric Supply Corporation with a subscribed capital of over £500,000, and plans to extend operations over a very large part of London, whose large station at Deptford and 10,000 volts transmission lines foreshadowed modern electricity supply practice. Another case is the lighting of Kensington Court, which Colonel Crompton, one of the residents, started in 1886. This grew into the Kensington and Knightsbridge Electric Lighting Company, which was in the 1890s one of the large and successful supply companies. The Metropolitan Electric Supply Co. started by acquiring the Whitehall Electric Supply Co. which had been formed to light Whitehall Court and neighbouring buildings, and the Rathbone Place power station, a private undertaking. The company rapidly expanded supply and in a few years of starting had added two large power stations to those two. Clubs, theatres, and fashionable shops were also ready to take a supply of electricity for lighting and there were successful
power stations established from the beginning on a fairly large (at the
time) scale. The first company with a provisional order which bore fruit
was the Chelsea Electric Light Company, which commenced operations in 1889,
its order having been granted in 1885. The St. James and Pall Mall
Electric Light Company found the London club area very profitable. The
Westminster Electric Supply Co. began supply in 1890 and soon had con-
structed three power stations. By the end of 1891 over £2 million had
been spent on power stations and their distribution networks in Central
London.

Table 11.
The Early London Electricity Supply Companies.

<table>
<thead>
<tr>
<th>Company</th>
<th>Commencement of supply</th>
<th>Capital expended in 1891</th>
<th>Revenue in 1891</th>
<th>Units sold in 1891</th>
</tr>
</thead>
<tbody>
<tr>
<td>London E.S. Co.</td>
<td>1835</td>
<td>£753,428</td>
<td>£15,561</td>
<td>457,300</td>
</tr>
<tr>
<td>Metropolitan E.S.</td>
<td>Oct. 1833</td>
<td>£436,926</td>
<td>£43,747</td>
<td>1,250,233</td>
</tr>
<tr>
<td>Westminster E.S.</td>
<td>Nov. 1890</td>
<td>£297,640</td>
<td>£19,455</td>
<td>573,385</td>
</tr>
<tr>
<td>Kensington and Knightsbridge Co.</td>
<td>Jan. 1837</td>
<td>£140,604</td>
<td>£13,188</td>
<td>385,050</td>
</tr>
<tr>
<td>St. James and Pall Mall Co.</td>
<td>April 1839</td>
<td>£139,458</td>
<td>£31,898</td>
<td>1,067,990</td>
</tr>
<tr>
<td>Chelsea Co.</td>
<td>Sept. 1839</td>
<td>£74,720</td>
<td>£10,172</td>
<td>290,458</td>
</tr>
<tr>
<td>Notting Hill Co.</td>
<td>June 1891</td>
<td>£67,845</td>
<td>£1,623</td>
<td>30,000</td>
</tr>
<tr>
<td>House to House (Brompton and Kensington)</td>
<td>Jan. 1889</td>
<td>£58,576</td>
<td>£8,328</td>
<td>230,242</td>
</tr>
</tbody>
</table>

Total 2,018,997 143,972 4,284,658
Source: Returns of the companies to the Board of Trade, The Electrician, January 1892.

1. Estimated by the Electrician from revenue and price data. No figures are given for the Charing Cross Co. (supply commenced 1890) and St. Pancras Vestry municipal undertaking (supply commenced 1891).

Capital expenditure on electricity supply outside London was very small. The only company of a size approaching the London companies was that at Liverpool. Although founded in 1883 it had remained tiny until 1888 when it had started to grow more rapidly. Even then at the beginning of 1891 it had no more lamps connected to its mains than the Westminster Company, which had only started supplying electricity in 1890. The London Electric Supply Corporation and the Metropolitan Electric Supply Co. had respectively 3 and 4 times as many lights connected. Otherwise in the provinces at the beginning of 1891 there were the small companies at Brighton, Eastbourne and Hastings, which were left over from the boom of 1882. In the West country several stations were started in the late eighties largely through the enterprise of one man, H.G. Massingham in 1886. He bought Thomson-Houston arc lighting equipment and used it in Taunton. The station was a success and was sold to a local company early in 1887. Under Massingham's auspices arc lighting spread to Bath and Exeter and by the end of 1891 Bath had 200, Taunton had 90 and Exeter had 60 arc lamps.

1. Electrician, Vol. 26 P 525. 27 February 1891.
2. Electrician, Vol. 22 P 385. 1 February 1889
3. Electrician, Vol. 26 P 275. 2 January 1891
A small number of incandescent lamps were also used in these installations. They grew subsequently but even by the end of 1895 their combined capital expenditure was only £70,000.

A more important development was the beginning of public supply in the large provincial towns. Here the municipal corporations played a large part, although the tempo of municipal enterprises was slower than that of the companies. Many corporations had applied for provisional orders in the 1880s but the first municipal power station was a contemporary of the London ones. It was built at Bradford and came into operation in 1889. But in general the municipalities were not anxious to rush into electricity supply. They did, however, build power stations very soon after their success had been demonstrated in London. In 1891 Brighton Corporation started supply in competition with the Brighton Company, in 1892 Dublin Corporation opened their power station, and in 1893 Blackpool, Bristol, Burnley, Derby, Dindee, Glasgow, Huddersfield, Hull, Kingston-on-Thames, Manchester, Whitehaven and Woolwich followed. Meanwhile public supply had been started in other large towns by companies, usually in advance of supply in the towns which were to have municipal electricity. Thus two power stations were built in Newcastle upon Tyne in 1889 and 1890, Cambridge, Oxford, Preston and Sheffield in 1892 and Leeds and Norwich in 1893. Often where the corporations had been a little slow but nevertheless interested in public supply, and a company had started operations, the corporation bought it out. This happened in Bath, Liverpool and Southampton in 1896, Sheffield and Leeds in 1898 and Birmingham in 1900. By 1900 the general pattern in the provinces
was established: the large towns had municipal supply, while the small towns were in the hands of companies.

The end of 1895 is quite a good statistical vantage point from which to view the very beginnings of electricity supply in this country. For the first time there are good overall statistics. These are summed up in Table 12.

Table 12.

Early Electricity supply undertakings i.e. those which began supply before the end of 1893.

Position as at the end of 1895.

<table>
<thead>
<tr>
<th>Companies</th>
<th>Municipalities</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>London</td>
<td>4,016 (10)</td>
<td>124 (2)</td>
</tr>
<tr>
<td>Provinces</td>
<td>1,305 (24)</td>
<td>1,060 (14)</td>
</tr>
<tr>
<td>Total</td>
<td>5,321 (34)</td>
<td>2,184 (16)</td>
</tr>
</tbody>
</table>


The figures include some of my estimates.

The importance of London stands out clearly in the above table, as does the large size of the London companies. Although the quantitative importance of London declined later, nevertheless the London companies remained among the big undertakings. The other major
point to notice is that the provincial companies' undertaking was significantly smaller than the municipal undertaking: while the capital expenditure of the average provincial municipal electric supply undertaking was £75,700, that of the average company undertaking was only £54,400. This gap was to widen with time, as the big provincial towns were further developed by the municipalities leaving the smaller towns for the companies.

No good figures of capital expenditure are available until the end of 1895. However, the "Electrician" made contemporary estimates and I have combined them with estimates of my own from Garke's Manual. The resulting figures contain a certain amount of guesswork, and can only be an approximation to the truth. The margin of error could be as high as £0.5 million, but is probably less.

Table 13.

<table>
<thead>
<tr>
<th>Year</th>
<th>£m.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1889</td>
<td>0.7</td>
</tr>
<tr>
<td>90</td>
<td>0.8</td>
</tr>
<tr>
<td>91</td>
<td>1.2</td>
</tr>
<tr>
<td>92</td>
<td>1.3 - 1.5</td>
</tr>
<tr>
<td>93</td>
<td>1.3 - 1.5</td>
</tr>
<tr>
<td>94</td>
<td>0.6 - 1.6</td>
</tr>
<tr>
<td>95</td>
<td>1.4</td>
</tr>
</tbody>
</table>

1. See Appendix P 485.
One of the most important variables in electricity supply is the size of area served by one power station. This area has continuously expanded, the rate of expansion being closely allied to technical progress, and this expansion has caused many of the organisational difficulties in the industry. As we are discussing the beginnings of electricity supply it is worth asking why it should be economically desirable to have public supply at all, as opposed to the numerous "isolated" installations of the late 1880s. Not that these "isolated" plants disappeared - some did, but they were replaced by others, and by 1907 more electricity was generated by users than was generated in public supply power stations. There are two principal reasons for having a public supply of electricity. One is that big generating plant up to a certain size, is cheaper, both in capital and running cost than small plant. The limit of the economic size of generating plant has increased over time, as technical improvements have been made. The second reason is that the diversity of peak loads will increase the larger the number of appliances connected, even if these appliances are all the same kind - for example lights. Because electricity cannot be stored, the size of generating plant required is a function of the peak demand for the appliances connected. But as electrical appliances are nearly always used intermittently the probability that they will all be switched on together is a decreasing function of the number of appliances. That this latter factor is of as wide and continuing a general application as the former can be seen from the great saving of generating plant which was made possible by
the construction of the national grid in the 1930s. However against these savings due to centralised generation there is the cost of the distribution network. A distribution network is very expensive; of the capital expenditure of electric supply systems about 40% was spent on the mains during the whole period up to 1914. Transmission and distribution costs could be reduced in three ways. Firstly the transmission voltage could be raised, thus reducing the cross-sectional area of the conductor. Secondly better insulating materials could be used. Thirdly cables could be made easier to lay. Also a distribution network involves a great deal of switchgear. This becomes more difficult to design, and more expensive the greater the voltage, but also the greater the total power transmitted, because faults on a system carrying a lot of power will cause enormous mechanical strains on switches. Inadequate switch gear means that faults can cause considerable damage to machinery and mains, and breakdowns are proportionately more expensive with bigger plant. Having made these general comments we can go on to discuss these variables in the years around 1890. The cost per KW of generating plant fell as the size of plant increased, up to a size of about 100 KW. Even this size was relatively big for the time. Some of the early Edison dynamos had ranged up to this size and on the Continent Crompton had installed 125 KW machines. J.E.H. Gordon

had built 350 KW alternators for the G.W.R. in the middle 1880s but these machines were not successful and disillusioned even Gordon himself. S.Z. de Ferranti was using bigger machines, of about 450 KW, at the Grosvenor Gallery in 1887, but his predilection for using the largest machines possible was not commercially very successful, partly because of their high initial cost. Most dynamos were smaller than 100 KW, and many of the early London companies started on dynamos of 50 - 100 KW. Bigger units seem to have been slightly more expensive to build and because of the much greater mechanical strains involved, more liable to break down. Breakdowns meant interruption of supply which was undesirable partly because of the expense of repair, but more because it was the best way to lose customers. Also heavy machinery was unsuitable for power stations in central residential districts. Large reciprocating engines made considerable vibration and noise and neighbours attempted, in several cases successfully, to get injunctions against a company causing a nuisance in this way. To build stations outside the residential areas would have demanded a revolution in technique. Ferranti attempted such a revolution which is better discussed later. It was not however

There was little point in having more than 8 - 10 generating units in each power station. If it was a d.c. station and all the plant would be operated connected in parallel, fuel economies could be achieved if about 8 units were installed, but no further economies could be realised with more. In the case of a.c. plants where machines could not at first be coupled together there was less scope for saving fuel by using several generators from the same boilers. There were economies of scale in buildings and boilers, but again not where there were more than about 8 - 10 units.

Then of course there was the question of the cost of distribution. An 800 KW power station would serve about 26,000 8 c.p. lights. In the provinces in the very early days one could not hope to get more than this connected in the central area. On the outskirts the cost of distribution raised electric lighting to a level well above that which could be achieved in quite small isolated plants. In London demand was much greater but it was clearly cheaper to duplicate power stations after the limit of generating economies had been reached.

But to make even the small stations of the early 1890s economically feasible required attention to the distribution network. Electric lighting in this country was primarily by incandescent lamps. It was at the time impossible to manufacture one to run on a circuit of more than 100 v. But the cost of 100 v. mains was excessive. The Edison 3 wire system was one technique of substantially reducing the cost of mains by permitting a doubling of the transmission voltage and
a further refinement on this was the more complicated, but even cheaper, Siemens 5 wire system. With such voltages it was not economical to have transmission mains more than a mile long. It was difficult to raise the transmission voltage further on a d.c. network, although this was attempted. There were two main techniques. One was to use accumulators as voltage transformers. They were placed in sub-stations, charged at a high voltage and discharged at low voltages. Crompton used this system at Kensington Court, and it was also used by the Chelsea Electric Supply Co. These battery systems enabled voltages of up to 500 v. to be used in the trunk mains, and also enabled electricity to be stored. The other technique was to use continuous current transformers, which were a generator and a motor coupled together. The motor was driven by current from the mains at up to 1000 v. and this drove a low voltage generator for the lighting supply. This was the well known "Oxford" system, pioneered by Thomas Parker, then chief electrical engineer of the Electric Construction Corporation.

A much better system of voltage transformation was the use of alternating current and the static transformer. Although the principle of the a.c. transformer goes back to Faraday's discovery of electro magnetic induction, the realisation of its economic value in permitting high transmission voltages and a simple change to low voltages for use was of very recent discovery. Gaulard and Gibbs had patented a transformer in 1832 which was intended to be used as a device for maintaining a constant current for arc lamps irrespective of the number in the circuit.

1. J.A. Fleming, Alternating Current Stations, Electrician Vol.27 Pp 582 - 8
25 September 1891
They do not seem to have appreciated its value to change voltages and permit high voltage transmission. The first people to do this were Zipernowski, Bardi and Blathy, the engineers of Ganz & Co. in Budapest. By 1885 they had a system of transformers connected in parallel used to transform voltages. In the United States George Westinghouse saw that Gaulard and Gibbs transformers could be developed in this way and by the spring of 1886 Stanley, Westinghouse's electrical engineer, had a practical system of parallel connected transformers in operation. In England S.Z. de Ferranti saw exactly the same point. Sir Coutts Lindsay had installed Gaulard and Gibbs transformers in the Grosvenor Gallery in 1885 when putting his temporary installation on a permanent footing. But the system was unworkable and Ferranti, who at the age of 21 had already made a name in alternator design, pointed out to Lindsay the superiority of the Zipernowski transformer. He was commissioned to change the system and in 1886 completely redesigned it, and replaced the existing dynamos with his own alternators. Generation was at 2400 v. and the current was transformed down to 100 v. for use.

Thus a.c. had considerable advantages for transmission and distribution. Mains cost less, static transformers were much cheaper and depreciation due to wear and tear was less than for rotating d.c. transformers or batteries. Also their operating efficiency was higher; this not only saved fuel, but more importantly, reduced the amount of generating machinery required per KW of maximum demand. But to offset this a.c. generating plant was very markedly inferior to d.c. plant.

2. Letter from G.L. Addenbrooke to Mrs. Ferranti, 20 October 1931. Ferranti private files m.s.
Early electrical engineering had concentrated on direct current. It was better for arc lamps and thus the arc lamp pioneers had used it. In the late eighties and early nineties it was much better understood. J.E.H. Gordon, one of the early pioneers of a.c., after his experience with a.c. at Paddington, turned away from it on account of its complications and advocated d.c. for the Whitehall power station of the Metropolitan Electric Supply Co. D.C. plant was considerably cheaper; a.c. plant could cost from half as much again to twice as much in the late 1890s. The efficiency of alternators was lower than that of d.c. generators and this meant more boiler and engine power per kW of maximum demand. Also running costs were much higher with a.c. than with d.c. In the early days alternating current stations could consume 2 - 3 times as much coal per unit generated. In 1891 the Electrical Review stated that the average coal consumption of a.c. stations was 20 - 25 lbs. per kWh compared with 10 lbs. for the d.c. stations. In 1894 when a.c. engineering had been intensively cultivated for some years Crompton estimated the average thermal efficiency of 7 a.c. stations at 2.31% while that of the d.c. stations was 3.06%. This was largely due to the difficulties of running alternators in parallel. Although Hopkinson had shown in 1894 that parallel running was theoretically possible, it was rarely done until the middle and late 1990s and then sometimes with some reluctance. A number of early stations ran alternators in parallel.

2. Quoted by R.H. Parsons, *op.cit.*, P 133.
occasionally, a number had no provision for doing it at all, each machine being connected to a section of the distribution network. As a lighting load has a sharp peak in the early evening, but is otherwise very low this meant that each engine and alternator was running light most of the time. This was very extravagant with coal. Often to make paralleling easier a rope drive was used, which again increased the coal cost. D.C. machines were usually directly coupled to engines and could be easily worked together. Thus each engine could be kept on nearly full load, extra engines being brought into operation and shut down as the load rose and fell. Crompton reckoned that 8 machines per power station could give the best fuel results.

In the early 1890's engineers engaged in a great a.c. - d.c. controversy known as the "Battle of the Systems". In areas of low supply density it was agreed that a.c. was better. Crompton himself - the great d.c. protagonist - put down a.c. plant for the lighting of Chelmsford in 1890. But in the areas more populated with customers the question was unresolved in the nineties. It is however probable that d.c. was slightly to be preferred. The major reason for this was that there were not enough economies of scale in generation for it to be economical to think in terms of a big distribution network. Only with very big stations is high voltage a.c. transmission a great advantage. The early a.c. stations used about 2000 v. in the primary
mains compared with d.c. voltages of 500 - 1500 v. When there was no
point in building stations above 1000, 2000 and 3000 KW, which was about
the minimum efficient size in the late eighties, early nineties and
middle nineties respectively, and the area of supply was densely
populated with customers, the length of mains which one would have even
at 2000 v. was relatively short. The possibility of using accumulators
with d.c. supply but not with a.c. perhaps turned the balance in favour
of the former. It is not likely that they reduced costs, probably the
reverse. Few people seemed to know about the costs of accumulators,
either their initial costs or the cost of maintenance, or about their
efficiency and reliability. Some people put great faith in them, some
disliked them intensely. Of all cost estimates those concerning
accumulators vary most and are most disputed. Some people advocated
using them to meet the stations' peak demand, thus economising on other
plant, but their high first cost and high rate of depreciation meant that
capital costs per KW maximum demand were as high with accumulators as
with generating machinery or even higher. Some stations used them at
night when the generating machinery was shut down, but this was probably
only thought profitable because inadequate capital charges were calculated.
Accumulators declined with the rise of big stations in the early 20th
Century, partly because they continually failed to fulfil the reiterated
promise that sanguine engineers made on their behalf and partly because
other plant became much more reliable. But in the early days they did
ensure regularity of supply by providing a standby when the other machinery
broke down. Early plant could be very unreliable and any accounts of the
operations of early power stations stress the endless faults and makeshift devices one had to use to keep the plant going. As one can see below from the case of the London Electric Supply Corporation, interruption of supply caused customers to melt away. In the event most of the London companies and most of the undertakings in the big towns adopted d.c. leaving a.c. for the areas with low consumer density. Naturally there were exceptions like the Newcastle Electric Supply Co. and the Metropolitan Electric Supply Co.

Had it been profitable to supply over a wide area, a.c. would have been the better system to choose. There was only one attempt to do this, that of the London Electric Supply Corporation, but this is a pioneer attempt, which is in itself sufficiently important to merit discussion, and provides an illuminating contrast with contemporary practice. Ferranti's first achievement was the remodelling of the Grosvenor Gallery plant. He constructed for the first time in this country an a.c. transformer system using 2400 v. in conjunction with his own 450 KW alternators, with a generous overload capacity. These dynamos seem to have been the biggest in the country at the time. This in itself put Ferranti in the forefront of the pioneers, but he was not content to rest there. He argued that there were still very considerable economies of scale to be gained from much larger generating plant. The other pioneer advocates of a.c., Westinghouse and Stanley in the U.S., the Ganz engineers on the Continent, and Gisbert Kapp in England were content

1. See R.H. Parsons, op.cit.,
with 2000 v. transmission but Ferranti wanted to go much further. He argued that big plant was cheaper in first cost and running cost than small plant, that facilities for handling fuel and oil were very bad in the centre of the crowded Metropolis, that expansion of the small stations then in favour was impossible and even that they might be closed down as a nuisance. Savory & Moore did in fact in 1889 obtain an injunction to prevent the running of heavy machinery at the Grosvenor Gallery. Ferranti was moreover impressed by the action of the gas companies in moving their works out to Beckton and Rotherhithe. He decided on Deptford as the best place to put his power station. But as this was some miles out of London the transmission pressure had to be very high and Ferranti proposed to use the then fantastic pressure of 10,000 v., at a time when many authorities considered that insulation for more than 2000 v. was impossible.

The conception of the scheme was of breathtaking originality, and earned for Ferranti the title of "the Edison of England". It involved a complete departure from existing practice; nearly everything had to be designed completely from scratch. First there was the question of generating plant. This had to be big and Ferranti proposed five giant alternators of 7500 KW capacity, well over ten times the size of anything constructed at the time and about seventy times the size of the usual generating unit. While they were being built he constructed 800 KW alternators which themselves were very big for the time. The 7500 KW machines were to be enormous, although they were never finished. The massive reciprocating engines were to be made by Messrs. Hick, Hargreaves & Co. Ltd., of Bolton, who had built the smaller engines for Deptford.
Their crankshafts were forged from steel ingots weighing 75 tons each, these being the heaviest ingots cast in Great Britain at that time. The fly wheel alternators were to weigh 575 tons each and were to stand 45 feet high. Their casting was such a large job that Krupps of Essen were unable to promise delivery in less than 3 years, and so the work was undertaken in England with specially constructed tools. Apart from the casting the alternators were being made entirely at Deptford under Ferranti's supervision with special lathes and other tools. The building also had to be on a massive scale as opposed to the other power stations of the time, with light machinery which could be housed simply, in some cases, in existing buildings. It was not only the electrical machinery that Ferranti had to supervise, he also designed a multiple steam pipe for the boiler plant while working at Deptford, which was an improvement on existing steam practice. Ferranti's transmission system was if anything more original still. No one had ever designed a transformer to deal with 10,000 v., and so Ferranti built one himself and had to devise his own way of testing it as no adequate testing instruments were available at the time. For his cables Ferranti chose jute insulated concentric cables manufactured by the recently formed Fowler-Waring Company. The cables from Deptford were laid along the railway track which was simpler than getting authority to put them underground and probably much cheaper. But although the


Fowler–Martin cables were electrically satisfactory, they were very susceptible to catching fire from the sparks and cinders of passing engines. So Ferranti came to the conclusion that he must design and construct his own mains. He chose a concentric cable insulated with paper. The use of paper as a dielectric for power cables was a notable innovation and was extremely valuable for high voltage mains. The revolutionary design of his cables was opposed by the Board of Trade, and to convince them of their safety Ferranti devised a test whereby one of his assistants held a chisel which was then driven through the mains. The assistant survived and the Board of Trade were satisfied. Eventually Ferranti overcame all the engineering difficulties, solving the host of small problems which always arise when innovations of this magnitude are being carried out. By March 1891 he was able to report to his Directors that "no engineering or electrical difficulties whatever have arisen which I have not been able to overcome, and at the present moment I know of no weak points in your system." By this time Grosvenor Gallery was a substation and all current was generated at Deptford.

The Deptford scheme was a work of genius. It was a magnificent engineering achievement, but was also more than that. For it was the first embodiment of the modern system of electrical supply with large generating stations and high voltage transmission. The title of the "Edison of England" was a deserved one, for Ferranti had combined the same quality of vision with the same quality of engineering ability that Edison had showed in New York City eight years before. Yet the London Electric


2. Engineers Report to the Directors of the L.E.S. Corporation. 1 March 1891
Supply scheme was commercially a failure. By 1904 it was in the hands of the Receiver, in 1905 its capital was reduced by a third, and despite this no dividends were paid on the ordinary capital until 1905, by which time the other London companies had been paying handsome dividends for some time. This was not because of the engineering of the system. Ferranti was right in saying that there were no weak points. In 1912 the 800 KW engine alternators and the original cable were still in use. The huge 7500 KW machines were never built but in 1925 the company showed its confidence in Ferranti machinery by buying a 1000 KW alternator from him.

The immediate cause of the financial failure of the Deptford scheme was that in its early years it was run very far below capacity. Ferranti himself later attributed the failure of Deptford to the action of the Board of Trade in carving up London for electricity supply purposes into small areas.

The Board of Trade had held an inquiry into electricity supply in London in 1939, when all these schemes for public supply were about to be put into practice. The basic philosophy behind the recommendations of Major Karindin who conducted the inquiry seems to have been firstly that any large scale monopoly of supply was undesirable and, secondly, that customers ought to have some choice of supplier. Major Karindin seems to have been impressed by the great argument between engineers as to the relative merits of a.c. and d.c. and so recommended that customers should if possible have a choice between the two. This affected the London Supply Corporation.

1. Letter to the Engineer, December 1929. Ferranti private files.
on both counts. The area of supply granted to them by the Board of Trade was much less than they applied for and in the area north of the Thames, where most of the demand existed, provisional orders were also granted to competing d.c. companies. As might be expected the Deptford scheme had bad teething troubles. There was a fire at the Grosvenor Gallery sub station in November 1890, which caused a shutdown for three months, just when people wanted lighting most. On the eve of the fire there were 38000 lamps on the company's mains; when supply restarted in February 1891 only 9000 remained. The following autumn the system went over to the full 10000 v. transmission and this caused numerous faults and interruptions of supply on many occasions. In November 1891 supply was interrupted for four days. By the end of the year there were only 2 36000 lamps connected. After this the plant became more reliable, but the damage was done; once the competing d.c. companies had distribution networks in most of the street of the area, it was very difficult to break in. Table shows how slow the growth of the London Electric Supply Corporation was compared with two of its big rivals. The Westminster Co. operated as a competitor in some areas. The teething troubles of the system seem to have lost Ferranti the confidence of the directors. Of the original subscribed capital in 1887 of £535,000, £220,000 was put up by Sir Coutts Lindsay, another £48,885 by Lord Wantage and nearly the

1. Report of L.E.S. Corporation for 1891. Electrician Vol. 28, 10 587 - 8 1 April 1892.

whole of the rest by 26 other shareholders. Ferranti had obviously captured the imagination of Lindsay and Wantage for at first they backed him against nearly all engineering opinion at the time, which regarded Ferranti's scheme as quite mad. But by 1891 their financial resources were becoming exhausted. The shares stood at such a discount that they could not raise money on debentures, and their great gamble did not seem to be coming off, especially after the Marindin report and the Grosvenor Gallery fire. In August 1891 Ferranti was dismissed and it was decided not to proceed with the 7500 kW alternators.

Table 1.

<table>
<thead>
<tr>
<th></th>
<th>1891</th>
<th>1892</th>
<th>1893</th>
<th>1894</th>
<th>1895</th>
<th>1896</th>
<th>1897</th>
<th>1898</th>
</tr>
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<tbody>
<tr>
<td>London Electric Supply</td>
<td>38</td>
<td>36</td>
<td>66</td>
<td>66</td>
<td>74</td>
<td>100</td>
<td>120</td>
<td>124</td>
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<tr>
<td>Metropolitan Electric Supply Co.</td>
<td>43.5</td>
<td>86</td>
<td>128</td>
<td>164</td>
<td>204</td>
<td>256</td>
<td>310</td>
<td>354</td>
</tr>
<tr>
<td>Westminster Co.</td>
<td>12</td>
<td>64</td>
<td>100</td>
<td>132</td>
<td>168</td>
<td>210</td>
<td>250</td>
<td>270</td>
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</tbody>
</table>

* November 1890.

Source: Electrical Trades Directory 1893.

1. F. Bailey. The Life and Work of S. G. de Ferranti, 1864 - 1930
   Address to the Electrical Power Engineers Association 1931.
   Privately printed by Ferranti Ltd., Hollinwood.
Government policy and lack of finance is then sufficient reason for the failure of the scheme, but it is worth trying to see whether it would otherwise have succeeded. There are two matters to discuss. One is whether, had the scheme been completed, supply would have been cheaper than from the small stations which provided electricity for most Londoners. The other is whether even if electricity from Deptford had been only a little more expensive than it could have been from elsewhere, much of the chaos which quite quickly developed in London's electricity supply might have been avoided.

It is difficult to do much more than approach an answer to the first as there are not even estimates of how much a completed Deptford would have cost. Also to make matters worse no figures of capital expenditure from 1891 to 1893 exist. The actual Deptford had a very high capital expenditure per lamp connected. In 1890 it was £17.2. By 1898 it had fallen to £7.1 but in the interim the capital had been reduced by 1/3 and fixed assets were probably written down by a similar amount. In 1891 capacity was about 90,000 lamps, although to supply them properly more money would have had to have been spent. Hypothetical capital cost per light would thus be at least £8.5 - £9, probably more allowing for connecting consumers to the mains. But a large sum of money must already have been spent on the two 7500 KW alternators, which would have brought capacity at the power station up to about 340,000 lamps. How much more would have had to be spent on them, and how much on connecting the lamps to the mains cannot be known but it is scarcely conceivable that the total could amount to less than £4 - 5 per lamp. Even then it was only

1. Probably about another £50,000.
approaching the actual cost per lamp of the other companies as can be seen from Table.

Table 15.
London Companies: Capital Expenditure per lamp.

<table>
<thead>
<tr>
<th>Company</th>
<th>Number of lamps</th>
<th>Capital Expenditure £000</th>
<th>Capital Expenditure per lamp £</th>
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</thead>
<tbody>
<tr>
<td>London E.S. Corporation</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>1890 actual</td>
<td>33</td>
<td>653</td>
<td>17.2</td>
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<tr>
<td>1891 estimate</td>
<td>90</td>
<td>768</td>
<td>8.5-9</td>
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<tr>
<td>Chelsea</td>
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<td></td>
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<tr>
<td>1891 actual</td>
<td>26</td>
<td>75</td>
<td>2.9</td>
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<td>House to House</td>
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<td></td>
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</tr>
<tr>
<td>1891 actual</td>
<td>20</td>
<td>53</td>
<td>2.9</td>
</tr>
<tr>
<td>Kensington and Knightsbridge</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>1891 actual</td>
<td>36</td>
<td>140</td>
<td>3.9</td>
</tr>
<tr>
<td>Westminster</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1891 actual</td>
<td>64</td>
<td>297</td>
<td>4.6</td>
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<tr>
<td>St. James and Pall Mall</td>
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<td></td>
</tr>
<tr>
<td>1891 actual</td>
<td>38</td>
<td>139</td>
<td>3.7</td>
</tr>
<tr>
<td>Metropolitan</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1891 actual</td>
<td>86</td>
<td>487</td>
<td>5.7</td>
</tr>
</tbody>
</table>

* Later fell.

For the years 1894 - 6 inclusive for 10 London undertakings excluding the London E.S. Corporation the unweighted average cost per lamp connected was £3.4.
Had the original scheme been adhered to and all five of the 7500 KW alternators been constructed capital costs might have been smaller, but probably not by much. It is more likely that they would have been more expensive per KW than smaller plant. Reciprocating engine alternators of this size were never built. In 1905 Manchester Corporation bought two 4000 KW reciprocating engine alternators, which were said to be the largest in any power station in Europe. But this was the limit and all bigger subsequent units were turbine driven.

High capital costs could be justified by much lower running costs. But running costs with this plant were unfortunately high and would have been even higher with the very large machines proposed. Ferranti wanted to build his large station partly because large engines would use less coal per KWh generated than small ones. But on the other hand engines running on a light load were very wasteful of fuel. The combination of the sharp short peak of the lighting load and the difficulty of running the alternators in parallel meant that the engines were on a light load much of the time. A fortiori the 7500 KW machines would have been more wasteful. As opposed to this what Crompton had learnt from his experience of the running of the early power stations was that the way to reduce coal costs was to divide the station load between about eight machines and so run them as much as possible on full load. This question of fuel economy and the fluctuation of the lighting load seems to have been neglected by Ferranti. The problem of coal costs would have been solved if the London Electric Supply Corporation had had a sufficiently high rate of growth. Also
capital costs would have been lower if the full station had been built because the costs of innovation would be more widely spread. Even then it is not likely that the latter would be even as low as those of other stations. On this point, however, Ferranti seems to have over-estimated the rate of growth of demand. Deptford was planned for one million lamps and by 1898 the number of lamps in London had topped this mark. The London Electric Supply Corporation accounted for only 10% of these, but even given more liberal treatment by the Board of Trade could not have hoped for much more than half of them. It is difficult to imagine that Deptford would have had one million lamps before 1900. And as it would probably not have sold electricity any more cheaply, the rate of growth of supply would not have been higher than it was.

Ferranti's scheme foreshadowed future electricity supply practice. Could it then be argued that it would have been better to establish electricity supply on his lines even though in the 1890s this was perhaps more expensive than the methods used? There are three points to be considered here. The first concerns future technical progress. Later bigger generating sets were developed which were cheaper than the small ones of the early 1890s. Transmission pressures were raised, and the cost of supply fell. If Ferranti's scheme had been tolerably successful it might have stimulated electricity supply engineers and electrical manufacturers to devote more effort to increasing the size of generators. English engineers do seem to have been excessively conservative in the later 1890s, and by 1900 English electrical engineering was very backward. There was particular backwardness on the a.c. side.
There are however other factors which contribute to this.

Secondly if a supply system is committed to small stations and d.c. networks this might be more expensive some years later, than if a.c. and big plant had both been adopted from the beginning. This would be the case while the costs of wholesale conversion were above the present value of expected future cost savings. But this could only be important with fairly slow technical progress, and the losses to the community would be small. Also as demand was growing it was more a question of expansion than scrapping. New, efficient machinery could be installed and old machinery used for meeting the peak load. When there was no more space in existing power stations big ones could be built outside the town, and the old ones used as sub stations. The trunk mains could be a.c. and converting plant put in the old power stations, thereby using the same old distribution network.

The third question is organisational. The continual growth of the optimal supply area meant some amalgamation or supersession of companies was desirable. In the event this was difficult. This problem really arose, however, only because of the inadequate public utility control of the time. It will be later argued that a good case could be made out for large private monopolies in electricity supply. But it is clearly not the only way the problem could have been dealt with.

All told the late eighties and early nineties were a period of much exciting innovation in British electricity supply. Although public supply started late in this country there was little general experience of large scale supply anywhere in the world. In the U.S.
where electric lighting had developed most rapidly, most power stations were very small. By 1891 the average U.S. undertaking had 2 - 4,000 lamps connected. Only in New York, Chicago, and Boston in the late eighties were there stations comparable in size with the ones being planned in Britain. The quality of English engineers was high; there were many exciting improvements in machinery and mains. The industry was in the hands of engineers and they were able at this time to find enough capital to carry out their schemes. The general cyclical upswing in the economy from 1897 made borrowing easier. This was reinforced by the electric lighting Act of 1888 but even without this Act the abundant general supply of funds relative to demand made it easy to get capital. They had learnt from their mistakes in the early 1880s and put electricity supply in a sensible economic position - one where the factor endowments of the British economy were properly understood. There was considerable co-operation between electrical supply undertakings and the electrical manufacturers; in many cases the same people were involved in both. Crompton planned the Kensington and Knightsbridge Company and was also manufacturing some of the plant he was to use there. Ferranti ran a small manufacturing business all through the time he was working at Deptford. The Electric Construction Corporation headed by Thomas Parker designed the Oxford plant and also constructed the electrical machinery for it. The Brush Company designed and manufactured the plant for the City of London Electric Supply Co. and was responsible for putting the

1. See H.C. Passer, op.cit., PP 30, 121 and 150.
system on its feet. Technical change had proceeded rapidly in lowering costs and it was clear that more progress would take place. Thus in the early 1890s one could be really quite optimistic about the future.
Chapter 3.

Electricity Supply 1896 - 1914.

By 1896 electricity supply was firmly established in this country. The experience of those places which had pioneer stations showed that the demand existed at prices which were profitable. Several municipal corporations had built power stations, and encouraged by their success many others followed. Capital expenditure by the municipalities rose from 1893 at an increasing tempo. The demonstration of the practical success of electric supply coincided with the rise of the municipal trading movement which reached its peak around 1900. Company promoters saw the success of the London and provincial companies and as soon as the cyclical upswing of the late 1890s made finance easier to get, company power stations began to be constructed all over the country. The pattern was typical of the one noted more widely by Schumpeter; first there was the pioneer innovation in the late eighties and early nineties and then with the next trade cycle came widespread imitation innovation. The volume of construction makes the investment of the very early days look very small indeed. In the three years 1897 - 99 inclusive as much was spent on public supply as in all the years before 1897; by the end of 1903, when the boom in electric supply construction was breaking, five times as much had been invested as before 1897. Thereafter the rate fell off, but continued throughout the period at an annual rate higher than any in the early days. Tables 16 & 17 give some relevant data; the latter shows the large number of new undertakings established and also shows that existing undertakings were growing rapidly enough for the average size to more than double itself.
### Table 16.

**Gross Investment in British Electricity Supply 1896 - 1913.**

<table>
<thead>
<tr>
<th>Year</th>
<th>Gross Investment £000</th>
<th>Additions to capacity of generating stations KW</th>
</tr>
</thead>
<tbody>
<tr>
<td>1896</td>
<td>1,972</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>2,472</td>
<td>20,236</td>
</tr>
<tr>
<td>8</td>
<td>3,285</td>
<td>33,446</td>
</tr>
<tr>
<td>9</td>
<td>4,822</td>
<td>60,175</td>
</tr>
<tr>
<td>1900</td>
<td>6,260</td>
<td>79,608</td>
</tr>
<tr>
<td>1</td>
<td>6,502</td>
<td>107,099</td>
</tr>
<tr>
<td>2</td>
<td>7,349</td>
<td>92,352</td>
</tr>
<tr>
<td>3</td>
<td>7,602</td>
<td>80,352</td>
</tr>
<tr>
<td>4</td>
<td>5,241</td>
<td>93,607</td>
</tr>
<tr>
<td>5</td>
<td>5,361</td>
<td>106,667</td>
</tr>
<tr>
<td>6</td>
<td>4,582</td>
<td>83,119</td>
</tr>
<tr>
<td>7</td>
<td>2,892</td>
<td>102,121</td>
</tr>
<tr>
<td>8</td>
<td>2,734</td>
<td>38,527</td>
</tr>
<tr>
<td>9</td>
<td>2,603</td>
<td>54,910</td>
</tr>
<tr>
<td>1910</td>
<td>2,722</td>
<td>70,350</td>
</tr>
<tr>
<td>11</td>
<td>2,805</td>
<td>97,019</td>
</tr>
<tr>
<td>12</td>
<td>1,633</td>
<td>134,487</td>
</tr>
<tr>
<td>13</td>
<td>3,335</td>
<td>117,332</td>
</tr>
</tbody>
</table>

**Source:** Calculations from Garke's *Manual of Electrical Undertakings*, 1907 and 1912. For methods of computation and estimation see Appendix P.486.
Table 17.

Average size of Supply Undertakings measured by KW capacity of generating plant.

<table>
<thead>
<tr>
<th>Year</th>
<th>Approximate Number of Supply Undertakings</th>
<th>Number with reliable statistics</th>
<th>Average size of undertakings in Col. 2. KW</th>
<th>Number of very large undertakings 10,000 KW and above</th>
</tr>
</thead>
<tbody>
<tr>
<td>1896</td>
<td>124</td>
<td>107</td>
<td>870</td>
<td>1</td>
</tr>
<tr>
<td>1900</td>
<td>210</td>
<td>133</td>
<td>1510</td>
<td>4</td>
</tr>
<tr>
<td>1903</td>
<td>332</td>
<td>275</td>
<td>1890</td>
<td>9</td>
</tr>
<tr>
<td>1907</td>
<td>380</td>
<td>297</td>
<td>3000</td>
<td>19</td>
</tr>
<tr>
<td>1912</td>
<td>591</td>
<td>295</td>
<td>4460</td>
<td>34</td>
</tr>
</tbody>
</table>

* Figures as at 31st December or 31st March the following year.

** A few very small undertakings may be missing.


By the end of 1903 all the bigger towns had electricity supply, although only a very small proportion of their populations had electric lighting. Before 1914 only a fringe had electricity in their houses. In 1910 L. Crouch calculated that in 80 inland towns electricity consumers were 1.5% of the population. As each house had only one consumer but

several users the percentage of the population using electricity was much higher: in industrial towns in 1911 the number of persons per house varied between 4.0 and 4.5 and this would make the number of persons using electricity in the big towns range from 6.1% to 6.8% of the population, excluding domestic servants. In 1903 the percentage was very much lower. Electricity was still very largely for lighting, although from 1900 on, public supply stations started selling electricity to the new electric tramways.

The municipalities played a very important part in this. Many municipalities had built new central stations in the late nineties and in the early years of the new century, while existing ones had been rapidly expanded. By the end of 1901, 61% of the connections to public supply mains (measured in KW) were to municipal mains, and by the end of 1903 the figure had risen to 68%. This was a peak figure but the percentage fell off only slightly in the following years before 1914.

Table 18.

<table>
<thead>
<tr>
<th>Year</th>
<th>Municipal Supply</th>
<th>Company Supply</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1896</td>
<td>N/A</td>
<td>N/A</td>
<td>115,000</td>
</tr>
<tr>
<td>1901</td>
<td>241,300</td>
<td>153,100</td>
<td>394,400</td>
</tr>
<tr>
<td>1903</td>
<td>448,141</td>
<td>207,626</td>
<td>655,767</td>
</tr>
<tr>
<td>1907</td>
<td>823,550</td>
<td>426,516</td>
<td>1,250,066</td>
</tr>
<tr>
<td>1912</td>
<td>1,218,585</td>
<td>630,424</td>
<td>1,849,009</td>
</tr>
</tbody>
</table>

Increases in demand for electric lighting seem to have been the main motive force behind the boom. There is no real evidence of supply stations being built ahead of demand. On the other hand, there is evidence that in some places at least the demand for electric lighting was consistently underestimated. Edinburgh Corporation found in 1897 that its estimate of revenue for that year was only 80% of the actual figure. In September 1897 Sheffield Corporation, having the year before bought the electric supply company gave notice that it could accept no more customers. The immediate cause was said to be the non-delivery of plant owing to the great engineering strike of that year, but their having no reserve capacity indicates the pull of demand. Early in 1893 Sunderland estimated its demand for 1898, 1899 and 1900; the estimates were 98%, 83% and 69% of the actual totals. But perhaps the best example of this is Manchester. Initially the system was built for 40,000 lamps and opened in July 1893; by March 1894, 40,000 were on the mains. Plant was put down for another 16,000 lamps; by March 1895, 66,914 lamps were connected. Thus a big increase was planned to bring total capacity up to 120,000 lamps; by the time the plant was ready to come into operation 143,998 lamps were connected. Then there was a rushed job to provide another 50,000 lamps capacity. There was no time to build a new station so some of the machines installed only

four years earlier were sold and once with a larger output installed. By the end of May 1897 there were 115,000 lamps connected and 12,840 on the waiting list. The rate of growth of supply was far above the Corporation's expectations, doubling as it was every year. It had been expected that the original plant would last for three years, but instead there were these hasty additions, and severe overloading of plant. Not that the matter ended there. Demand continued to increase so rapidly that in the early part of 1901 the electric lighting committee was at its wits' ends to know what to do to meet it. Thus they had to start on the extensions to the new Stuart Street central station before the first part was open. Not really until March 1903 was there thought to be enough plant for the next year or so.

Another piece of evidence to support the view that it was the pull of demand which determined the timing of central station construction is the attitude of the municipalities. Very ready to trade, yet careful to avoid speculative enterprise, they built fairly cautiously. They did not see the creation of demand as one of their functions at all.

The high demand for electricity for lighting in the late nineties seems principally to have been due to the growing appreciation of the advantages of electric lighting and to reductions in the price of electricity.

and to a lesser extent of light bulbs, during the 1890s.

Table 19.

The price of electricity for lighting 1893 - 1912.

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of undertakings in sample</th>
<th>Average price per 1,000 ft. (unweighted)</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1893</td>
<td>35</td>
<td>7.17</td>
<td></td>
</tr>
<tr>
<td>1894</td>
<td>54</td>
<td>6.90</td>
<td></td>
</tr>
<tr>
<td>1895</td>
<td>20</td>
<td>4.74</td>
<td>1.11</td>
</tr>
<tr>
<td>1912</td>
<td>20</td>
<td>3.63</td>
<td>1.17</td>
</tr>
</tbody>
</table>

Calculations from the Electrician and Engineer's Manual.

It may have been stimulated by the building boom which begins around 1895, and the general industrial boom of the late 1890s, characterized as it was by very heavy domestic investment. How important the building boom is, is difficult to say. For any new buildings the cost of electric lighting relative to gas lighting was much lower than for old ones, which were already carcaseed for gas. Also the initial cost of wiring old houses, as it had to be done by the consumer, could well be an obstacle, even if the adoption of electricity would be rationally justified. Electric supply mains were only laid in the middle of towns.

and thus all new building on the outskirts is irrelevant. But there was a considerable amount of reconstruction all over the country in the housing boom of the late nineties.

A large proportion of electricity was sold to shops and offices, and they would be stimulated by the upturn of the business cycle. Better business conditions would stimulate the remodelling of the bigger shops and they would be likely to install electric lighting as part of their modernisation schemes.

In this situation it was not in general to be expected that large scale plant, fully exploiting all possible economies of size should be laid down. Power stations had new plant put piecemeal into buildings designed for smaller plant; there was often no time to plan the whole system in an ideal manner. What makes this important is that the possible economies of scale were only potential. Planning and building bigger individual pieces of machinery was the responsibility of the engine, dynamo and boiler makers, but the planning of the system as a whole was in the hands of the electricity suppliers. Also they were the ones who had to decide to try new types of plant, whose delivery dates were longer than tried units. For by the middle nineties the design of power stations had passed out of the hands of the manufacturers of plant into those of consulting engineers, who were appointed to build and extend supply systems. With rare exceptions they were completely independent of the manufacturers.

The municipalities were used to employing consulting engineers for other works like buildings and sanitary schemes and naturally extended this to electricity supply. The optimum size of generating machinery was extended during the 1890s, as manufacturers were able to design larger units satisfactorily, reducing the cost per KW at the same time. But partly because of the factors mentioned above, the size of generating unit installed was a good deal smaller in general by the late 1890s than was the case in the United States or on the Continent of Europe. By September 1900, when American and Continental influence was becoming important, the Electrical Review commented that only in the last few years had British manufacturers had a demand for dynamos above 300 KW.

But apart from demand there was one factor on the manufacturing side which reinforced this tendency towards small units. This was the success of the high speed engine. Its development and use for driving dynamos was extremely valuable, and peculiarly British innovation. The utility of a high speed engine for driving dynamos was apparent from the very early days. The desirable speed of rotation of dynamos was high relative to that of most steam engines, 400 - 900 r.p.m. as against under 200. At first rope driving was adopted to provide the necessary gearing but the consequent loss of power made direct driving attractive. Direct driving with high speed engines springs from the co-operation between Crompton and Peter Willans.

Table 20.


<table>
<thead>
<tr>
<th>Year</th>
<th>All high speed reciprocating engines</th>
<th>Willans engines</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to and including</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1892</td>
<td>60 - 93</td>
<td>43 - 84</td>
</tr>
<tr>
<td>93</td>
<td>52 - 82</td>
<td>44 - 70</td>
</tr>
<tr>
<td>94</td>
<td>43 - 85</td>
<td>30 - 58</td>
</tr>
<tr>
<td>95</td>
<td>44 - 80</td>
<td>34 - 62</td>
</tr>
<tr>
<td>96</td>
<td>34 - 65</td>
<td>25 - 47</td>
</tr>
<tr>
<td>97</td>
<td>50 - 73</td>
<td>37 - 54</td>
</tr>
<tr>
<td>98</td>
<td>59 - 64</td>
<td>33 - 36</td>
</tr>
<tr>
<td>99</td>
<td>55 - 84</td>
<td>30 - 46</td>
</tr>
<tr>
<td>1900</td>
<td>70 - 75</td>
<td>39 - 42</td>
</tr>
<tr>
<td>01</td>
<td>45 - 49</td>
<td>22 - 25</td>
</tr>
</tbody>
</table>

1. Known to be high speed engines. Some small amount may be excluded. Percentages are given in a range because of the large number of prime movers of unidentified makers. The smaller percentage is of all prime movers; the larger one of identified prime movers.

Source: Calculations from the Electrical Trades Directory.

The range of the above figures is rather wide. Some check comes from other sources. In January 1892 the Electrical Review stated that 62% of the h.p. of prime movers in all British Central stations was in Willans high speed engines. Details were given on the same month of 45% of the total horse power installed, 80% of this was in the Willans engines.

The Electrical Engineers Central Station Directory gave details of prime movers installed up to the end of 1897. Percentages are:-

- All high speed engines: 55 - 59
- Willans engines: 39 - 42
in 1879 - 80, Willans was developing high speed engines for launches and yachts. Crompton was a mechanical engineer who had just become interested in electric lighting. Together they came to the conclusion that the generating set of the future would be a high speed engine coupled direct to a dynamo. They made their first central station installation using six 125 KW Willans-Crompton generating sets in Vienna in 1883 - 6.

Such was the success of the Willans engine that all the London d.c. central stations of 1888 - 92 used direct coupled Willans engines. Those high speed generating sets were initially cheaper than slower ones, and their fuel consumption was very low. As a result, high speed direct coupled units became standard d.c. practice for the 1930s. Willans engines retained their pre-eminence although other manufacturers also made high speed engines. These engines were admirable when small i.e., below 200 KW. But it was difficult to build bigger ones, and they did not work so well.

Even the big supply undertakings with more than 10,000 KW generating capacity had small generating sets. Many of them had a number of central stations. Several of the London companies had had several stations from the very early days. Perhaps the most extreme examples of the duplication of small plant are the Liverpool Corporation power station which as late as 1904 had 73 generating units aggregating 24,825 KW and

2. Ibid. P 105.
3. R.H. Parsons, op.cit. PP 72, 75, 78, 84, 97, 103, 107.
the Westminster Company which in 1903 had 49 units aggregating 9,330 kW in three power stations. But there were some big power stations which attempted to extend the frontier of scale economies. It is useful to consider them under two headings, first the big power stations of existing undertakings, and second those of the power companies, most of which were founded in 1900 and 1901. Discussion of the latter is best deferred to the next chapter.

As the load on the early stations in the centre of towns grew, and improvements in electrical machinery continued it began to be economically sensible for a supply undertaking to build a big new station some distance away from the centre of its supply area and transmit at high voltages. This was facilitated by three very important innovations, all products of the 1890s. The first was the introduction of polyphase alternating current. The second was the use of paper insulated cables. The third was the development of the Parsons steam turbine.

The initiators of polyphase a.c. were Professor G. Ferraris, Nikola Tesla and Von Dovilo Dobrowolsky. It was intensively developed in the United States, particularly by Westinghouse, who employed Tesla, but also by General Electric, and in Europe particularly by A.B.G.

1. See Technical Appendix.
4. Allgemeine Elektrizitats Gesellschaft, originally the German Edison Co.
who employed Dobrowolsky, and the Gerlikon Company. Quite apart from its
1 use of a 3 phase a.c. transmission line could reduce the copper cost of
2 the mains by 15%. 3 phase alternators were cheaper than ordinary a.c.
(single phase) machines. Also it was easy to convert 3 phase a.c. to
d.c. and thus high voltage transmission could be linked to the existing d.c.
distribution system and the new a.c. power station run in parallel with
the old d.c. one. This was not possible with single phase a.c. C.H.L.
Brown of the Gerlikon Company and Dobrowolsky demonstrated a 3 phase a.c.
transmission system at 30,000 v. over 110 miles from Frankfurt to Lauffen
as part of the Electrical Exhibition at Frankfurt in 1891. Over 300 h.p.
was transmitted, 74% of the power being received at the other end. This
gave a powerful impulse to the Niagara Scheme of 1895 when 10,000 h.p.
was generated at Niagara and transmitted at 11,000 v. 2 phase.

Very few English electrical engineers were in the 1890s at all
interested in polyphase a.c., and English manufacturing firms could see
no point in it at all. Electricity supply engineers were however more
progressive and one of the best, C.H. Worsdenheim, Manchester Corporation's
Chief Electrical Engineer, who had worked with Ferranti at Deptford, pointed
out to the Northern Society of Electrical Engineers in November 1897 that

1. 2 phase a.c. was also used in the early days. It was initially simpler than
3 phase but ultimately inferior.

3. See Technical Appendix.
4. J.A. Fleming, op.cit., p. 239.
conditions were now very different from those in the early years. Then, he argued, it was a question either of a cluster of consumers taking a fairly large amount of energy, gathered in a compact area, or of a number of isolated consumers scattered over an extended area. Hence the "battle of the systems". Now, however, he argued, both supply density is rising (more energy is demanded per mile of cable) and the area of supply is being extended. He preferred d.c. distribution; it was better for motors and arc lamps, and accumulators could be used. Each distribution network would be fed by d.c. or polyphase a.c. transmission lines, either from one large station or from several small ones according to local circumstances. Before he left Manchester Corporation in 1901 he had designed and built a 10,500 KW d.c. station and a 19,000 KW 3 phase a.c. station with high voltage transmission. The London companies by the late nineties had outgrown their small stations and they also built big stations some distance from their supply areas. In 1897 the Metropolitan Electric Supply Company decided to build a new station at Willesden; three 1,500 KW 2 phase alternators built by Westinghouse were installed and transmission was at 10,000 v. The Kensington and Knightsbridge Company and the Notting Hill Company combined to build a joint generating station which was opened in 1900. This worked 3 phase at 5000 v., the first high voltage 3 phase system in this country. A further step was taken by the Charing Cross Company which opened its new power station at Bow in 1902. This worked at 11,000 v. with 1,600 KW generating units, built significantly by the

1. See Chapter 6.
Lahneyer Company of Cologno. It is worth noting that although British electricity supply was adopting Ferranti's transmission pressure it made no attempt to build plant of the size he proposed. Thus the big power stations began to be established, but there is little doubt that this country was slow to adopt American and Continental innovations.

Paper insulated cables were first used for mains by Ferranti at Depford. They were the culmination of several attempts made in the eighties to improve cables. Telegraph and telephone cables were not suitable for electric lighting. Several alternatives were tried. Sometimes the improvements were in insulating material like the use of Vulcanised Bitumen or jute. Sometimes the improvements were in the general design of the mains, like the use of bare wires or rods suspended on insulators in an underground tunnel. But generally they all had the disadvantage either that the insulation was not satisfactory for high voltage operation or that they were rigid and thus expensive to lay. Then in 1883 Ferranti patented paper insulated cables. Paper was a cheap material, and cheap to apply. The Depford cables, the first power cables to use paper as a dielectric, were however rigid tubes. The paper insulation was rolled on in sheets 20 feet long. However Ferranti's patent also covered use of paper applied helically in strips. This method had also been used in the United States for telegraph cables. While on a visit to America

in 1889 J.B. Atherton noticed paper insulated telephone cables. He bought the British rights in 1890, and on his return to England in 1891 he formed the British Insulated Wire Company to manufacture paper insulated mains cables. In the same year Ferranti left Depford, and possessing the British patent of 1888 for paper winding was invited to join the board of B.I. Wire. In 1893 the company made some 11,000 v. concentric paper insulated cables for the London Electric Supply Corporation. They were similar to Ferranti's Depford cables with the additional advantage of flexibility. This meant that they were almost entirely manufactured at the factory, and could be simply and cheaply laid. Very few joints were needed. Thus the cost of high voltage mains was very substantially reduced, and thus the economies of scale in generation could be further used.

The third major innovation in electricity supply was the steam turbine. Here the attitude of the English power station engineers was somewhat ambiguous. It was the most important British innovation in electricity supply machinery made in this country before 1914. Often the successful ideas came from abroad, but this was entirely home produced, through the ability and determination of Charles Parsons.

1. 6th son of the third Earl of Rosso, who was an engineer and an astronomer, becoming a President of the Royal Society. Born 1854, educated at home by Robert (later Sir Robert) Ball the astronomer, at Trinity College Dublin and St. John's College Cambridge. He graduated from Cambridge in 1877 as Eleventh Wrangler. He was apprenticed for four years at the Elswick Works of Sir William Armstrong & Co. From 1881 - 1883 he worked with Messrs. Kitson & Co. of Leeds. In 1884 he became a junior partner in Clarke Chapman & Co. and took charge of the newly created electrical department. In 1889 he founded his own works in Newcastle-upon-Tyne. He was a great inventor and we are only concerned with some of his work. See R. Appleyard, Charles Parsons, London, 1933. R.H. Parsons, The Steam Turbine and other inventions
The basic idea of the steam turbine is very ancient and goes back to the machine built by Hero of Alexandria to open the doors of the temple. Several attempts were made to build steam turbine engines in the 19th century. But all failed because such engines only worked efficiently at enormous speeds. In 1884, Parsons patented the idea which was a complete solution to this problem, and built a turbine engine to his patent specification. His idea was to place a series of turbine wheels along a shaft. Steam passed through the blades of successive wheels losing a small amount of its pressure at each wheel. Because the energy in the steam was not instantly converted into rotating motion, but was used gradually, the speed of the turbine engine could be vastly reduced without loss of efficiency. The Parsons turbine of 1884 used, however, considerably more steam than a conventional steam engine for a given power, 129 lbs. steam per KWh while an efficient reciprocating steam engine would use about 20. By 1892 Parsons had improved the turbine until steam consumption was down to 27 lbs. per KWh, which although somewhat above that of the best reciprocating engines proved that the turbine was not necessarily wasteful. It seems to have been relatively less wasteful at small loads, which was particularly useful for electricity generation.

But the steam turbine was primarily a capital saving innovation. Its first cost was slightly lower than that of reciprocating engines when built in large sizes above about 500 - 100 KW. It was much smaller and...
lighter than large reciprocating engines. It is instructive, although rather extreme, to compare the 7500 kW turbo alternators which were installed at Deptford in 1912 with Ferranti's projected reciprocating engines. The latter would have been 3.7 times as wide, over 5 times as high and 0.9 times as long. As a result the cost of foundations and buildings was much reduced; it was about half that involved in installing large reciprocating engines. It was a much faster engine, which much reduced the cost of the dynamos driven by it: instead of the enormous fly wheel alternators driven by slow speed engines, compact machines could be used with only a fraction of the size and weight of the former. Also the turbine had a particularly useful characteristic for electricity supply; it would run for a short time at extremely high overloads. Thus the sharp peak of the electricity load could be met with plant whose normal capacity was perhaps only three quarters of the peak demand, very substantially reducing the cost per KW of maximum demand. Turbines would thus have been capital saving even at the same cost per KW of normal capacity as reciprocating engines.

During the 1890s steam turbines were used only in this country. This was partly because Parsons was an Englishman. The first turbo alternators were installed at the Forth Banks power station at Newcastle-upon-Tyne in 1889; the company was however formed by Parsons and his friends and the former was the managing director. In 1892 they were put onto the newly formed Cambridge Company's station; again Parsons
was the managing director, the company being formed by Parsons and Cambridge University friends. Other small turbines were installed but the most important turbine plant of the middle 1890s was that at the Metropolitan Electric Supply Company's Manchester Square Station in London. Here the Willans engines caused a great deal of vibration, which a whole series of expedients were powerless to eliminate. Neighbours complained of the nuisance and in 1894 obtained an injunction against the Company. But the station was saved by the installation of 350 kW Parsons turbo-alternators — more than twice the size of any hitherto built. These were however somewhat special circumstances, for in general the turbine displayed no very great advantages over the high speed engine when it was built in small sizes. Its superiority was over the big low speed engine and thus one would not expect the turbine to be widely installed until big generating units were used. English power stations were slow in installing big plant and thus it is not surprising that from 1900 - 1905 the pioneer big turbine installations were in the United States and on the Continent. The first big Parsons machines were built for the Corporation of Elberfeld in Germany in 1900, with a capacity of 1000 kW. The Westinghouse Machine Company acquired the Parsons patents in 1896 and rapidly developed them.

1. A.C. Ewing, Professor of Engineering at Cambridge conducted important tests on Parsons turbines in 1892, dispelling their early reputation of being "steam eaters". It is amusing to see that in electric lighting systems, as in other matters, Oxford should by comparison be the home of lost causes.

Brown-Boveri bought a licence immediately after the success of the Elberfeld machines, and again developed them rapidly. They were quickly followed by General Electric in the United States and A.E.G. and Siemens & Halske in Germany with different types of turbine. In both places big generating units were widely used and thus there was a bigger demand for large prime movers. It is however rather surprising to find that when English electricity supply engineers did build big plant, they used large reciprocating machinery, usually of foreign manufacture. The Metropolitan Electric Supply Company, despite its Manchester Square turbines, chose Westinghouse plant for its Willesden station. Wordingham at Manchester is an odder case. The specifications for the huge Stuart Street plant were issued in 1901. Turbines would almost certainly have been better, although their advantages in large sizes had only just been demonstrated. But as late as 1905 Wordingham, although extremely able and still under 40, told a House of Lords Committee that he thought turbines were a passing fashion. An example of really antiquated practice is provided by the Greenwich tramway power station of the L.C.C. opened in 1906. Four 3500 KW engine alternators were installed; 6½ years later it was realized that they were obsolete and two and two 8000 KW turbo alternators installed in the same space.

1. Founded in 1892 by C.E.L. Brown. The works were in Baden.
As R.H. Parsons has pointed out there was no real excuse for this as the Newcastle Electric Supply Company had had very successful 3500 KWP turbo-alternators running at Carville in 1904. Professor A.W.B. Kennedy, the consulting engineer to the L.C.C., had become an expert in designing successful small stations in the 1890s but by 1905 he seems to have lost his touch. Charles Morz's brilliant achievement at Carville is a pleasing contrast, and his plans for London, if allowed to be put into operation, might have revolutionised English power station practice. After the success of Carville, however, turbines did come to be used considerably for big plant. There was still considerable controversy about the merits of steam turbines, but it soon became generally accepted that turbines were better than reciprocating engines in sizes above 1000 KWP. Below 500 KWP reciprocating engines were said to be better.

There is rather inadequate information about the switch from reciprocating engines to turbines. By the end of 1903 at least 1500 KWP of Parsons turbines had been installed in British central stations. This was only 2.6% of total capacity. 15000 KWP is no doubt an underestimate but it is not likely that the actual figure was more than twice this. Between the end of 1903 and the end of 1907, 408,000 KWP of capacity

1. P 169.

2. This is confirmed by his evidence before the House of Lords Committee, on the Administrative County of London & District Electric Power Bill. There he said that 3 phase supply would, he felt certain, have ceased to exist in 15 years time. Q 4578.

3. E.R. Vols. 53 & 54 for a long controversy in the correspondence columns. Table on P 54 of Vol. 54 and Vol. 55 PP 1009 - 1010.
was installed in British central stations. By then there were 250,000 KW powered by steam turbines. Thus 53 - 58% of the capacity added in the years 1904 - 07 was driven by turbines. Table 21 shows that not until 1904 did the average size of generator rise above 500 KW. Thus turbines were largely used because large generating units were not used.

By the end of 1903 electricity supply undertakings existed in nearly all big towns. All towns but two with a population of more than 100,000 had electricity supply. Electricity was sold mainly for lighting. Supply stations were small on the average and distribution mains did not extend very far. As a means of lighting electricity was much less used than gas. When converted to a common basis, electricity seems to have provided 6,057 million 16 c.p. light hours in 1904, against 28,300 million supplied by gas. This was only 18% of the total but was considerably more than the 4% supplied by electricity in 1896. Yet during the years 1896 - 1904, the light hours supplied by electricity rose only by 5,185 million p.a. while those supplied by gas rose by 

1. Census figure minus 44,000 KW at Lots Road. The Census figure also includes any turbines in municipal tramway power houses. But there were very few turbines in municipal tramway power houses in 1907.

2. Depending on whether we take 15,000 KW or 30,000 KW as the capacity of turbines installed at the end of 1903.


4. Assuming a 16 c.p. electric lamp took 60 watts (3.75 w. per c.p.) and a 16 c.p. gas burner took 5.5 cu. feet of gas per hour. The calculator is very crude.
Table 21.
Average size of generators installed in British centrals stations 1883 - 1913.

<table>
<thead>
<tr>
<th>Installed up to the end of 1892</th>
<th>KW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Installed during 1893</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>35</td>
</tr>
<tr>
<td>5</td>
<td>96</td>
</tr>
<tr>
<td>6</td>
<td>103</td>
</tr>
<tr>
<td>7</td>
<td>129</td>
</tr>
<tr>
<td>8</td>
<td>156</td>
</tr>
<tr>
<td>9</td>
<td>120</td>
</tr>
<tr>
<td>1900</td>
<td>251</td>
</tr>
<tr>
<td>1</td>
<td>236</td>
</tr>
<tr>
<td>2</td>
<td>328</td>
</tr>
<tr>
<td>3</td>
<td>261</td>
</tr>
<tr>
<td>4</td>
<td>347</td>
</tr>
<tr>
<td>5</td>
<td>501</td>
</tr>
<tr>
<td>6</td>
<td>503</td>
</tr>
<tr>
<td>7</td>
<td>672</td>
</tr>
<tr>
<td>8</td>
<td>749</td>
</tr>
<tr>
<td>9</td>
<td>775</td>
</tr>
<tr>
<td>1910</td>
<td>488</td>
</tr>
<tr>
<td>11</td>
<td>641</td>
</tr>
<tr>
<td>12</td>
<td>924</td>
</tr>
<tr>
<td>13</td>
<td>1,113</td>
</tr>
</tbody>
</table>

Source: Calculations from the Electrical Trades Directory. For details see Appendix P. 510.
Table 22.

Electricity Supply. Sales, Million KWh.

In the first three columns figures are for the accounting year which most overlaps the relevant calendar year. In the fourth column figures have been corrected to a calendar year basis.

<table>
<thead>
<tr>
<th>Year</th>
<th>Lighting</th>
<th>Traction</th>
<th>Power</th>
<th>Total</th>
<th>Calendar year total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1895</td>
<td>37.8</td>
<td></td>
<td></td>
<td>37.8</td>
<td>37.3</td>
</tr>
<tr>
<td>96</td>
<td>52.3</td>
<td></td>
<td></td>
<td>52.3</td>
<td>51.6</td>
</tr>
<tr>
<td>97</td>
<td>70.1</td>
<td>1.2</td>
<td></td>
<td>71.3</td>
<td>70.6</td>
</tr>
<tr>
<td>98</td>
<td>88.5</td>
<td>0.6</td>
<td>3.8</td>
<td>92.9</td>
<td>91.4</td>
</tr>
<tr>
<td>99</td>
<td>124.0</td>
<td>3.2</td>
<td>4.4</td>
<td>131.6</td>
<td>127.6</td>
</tr>
<tr>
<td>1900</td>
<td>152.8</td>
<td>15.7</td>
<td>11.9</td>
<td>180.4</td>
<td>177.2</td>
</tr>
<tr>
<td>01</td>
<td>189.6</td>
<td>35.3</td>
<td>18.4</td>
<td>243.2</td>
<td>241.1</td>
</tr>
<tr>
<td>02</td>
<td>243.5</td>
<td>66.6</td>
<td>23.6</td>
<td>333.7</td>
<td>325.9</td>
</tr>
<tr>
<td>03</td>
<td>280.3</td>
<td>103.4</td>
<td>49.4</td>
<td>433.1</td>
<td>417.2</td>
</tr>
<tr>
<td>04</td>
<td>363.4</td>
<td>113.9</td>
<td>76.2</td>
<td>553.5</td>
<td>540.9</td>
</tr>
<tr>
<td>05</td>
<td>352.0</td>
<td>176.3</td>
<td>116.3</td>
<td>644.6</td>
<td>627.8</td>
</tr>
<tr>
<td>06</td>
<td>401.9</td>
<td>231.7</td>
<td>182.3</td>
<td>776.9</td>
<td>756.1</td>
</tr>
<tr>
<td>07</td>
<td>416.0</td>
<td>224.1</td>
<td>325.9</td>
<td>966.0</td>
<td>934.2</td>
</tr>
<tr>
<td>08</td>
<td>442.4</td>
<td>224.4</td>
<td>368.8</td>
<td>1035.6</td>
<td>1025.0</td>
</tr>
<tr>
<td>09</td>
<td>417.3</td>
<td>230.3</td>
<td>475.7</td>
<td>1123.4</td>
<td>1108.3</td>
</tr>
<tr>
<td>1910</td>
<td>482.9</td>
<td>227.9</td>
<td>562.8</td>
<td>1273.6</td>
<td>1250.0</td>
</tr>
<tr>
<td>11</td>
<td>437.0</td>
<td>287.2</td>
<td>681.4</td>
<td>1405.5</td>
<td>1384.4</td>
</tr>
<tr>
<td>12</td>
<td>507.3</td>
<td>277.1</td>
<td>884.4</td>
<td>1688.8</td>
<td>1614.0</td>
</tr>
<tr>
<td>13</td>
<td>695.8</td>
<td>280.0</td>
<td>1004.0</td>
<td>1980.8</td>
<td>1895.5</td>
</tr>
</tbody>
</table>

For details of calculations see Appendix. P 489.
Electric lighting was unfortunate in that by the time the cost of electric incandescent lighting had come down almost to that of gas burners, the incandescent gas mantle had been developed, which substantially reduced the cost of gas lighting. This may well account for the decline in the rate of increase of the consumption of electricity for lighting. As Table 22 shows the sale of electricity for lighting rose by 24.7% between 1897 and 1902 but only by 71.5% between 1902 and 1907. The invention of the metal filament lamp, which began to be used in large numbers from 1907 onwards redressed the balance again. The metal filament lamp used about a third as much electricity for a given light as did the carbon filament lamp. After 1907 the use of the metal filament lamp, the incandescent gas lamp and the use of gas for heating made measurements of the amount of light provided by gas and electricity quite impossible. Sales of electricity for lighting did not rise much (the rise may well be overestimated in Table 22). But the amount of lighting rose rapidly, and probably more than trebled between 1907 and 1912.

The figures for the sale of electricity for lighting include both incandescent and arc lighting. Most was for incandescent lighting. In 1907 incomplete figures were given of the sale of electricity for

1. No allowance has been made for gas sales for heating and power, which were small yet rising faster than sales of gas for lighting, or for the effect of the adoption of the incandescent gas lamp. These two effects would work in opposite directions.
lighting, separate figures being given for public lighting (chiefly arc lights in the street) and private lighting (chiefly incandescent lighting). Of the recorded total of sales for lighting went for public lighting. But there is a big difference between sales by company undertakings and by municipal undertakings. Only 3% of the sales of companies for lighting went for public lights, against 25% for municipalities. Municipal corporations were willing to use arc lighting in the streets when they operated the town's central station but were not anxious to buy electricity in large quantities from private central stations. After 1907 street lighting did not increase very much. Rather incomplete figures suggest that the amount of electricity sold for public lighting rose by only 17% between 1907 and 1912. By then arc lighting was at the end of its useful life. Just before the 1914 war the "half watt" incandescent lamp appeared. It was equal in output to the arc lamp, but used only half as much electricity. Also there was no need to change carbons. After the 1914 - 18 war it soon superseded the arc lamp.

As Table 22 shows sales of electricity for traction rose rapidly up to 1907, but then flattened as tramway construction fell off. Sales for power began to be important from about 1904 onwards. Most electricity for power was generated by users, public supply stations in

1. Which is 80% of my estimate for all sales for lighting.
2. 0.5 watts per candle power efficiency.
3. See Chapter 5.
general supplying small users who used motors intermittently. In this
most central stations built originally for lighting supply one different
from the power companies. The power companies sold a large proportion of
their electricity to a few big users.

The pattern of the use of electricity bought from central stations
to a large extent explains the fall in central station investment after
1903. In the late nineties capacity was a function of the lighting peak.
After 1907 these two loads ceased to grow. The rising power load seems
to have had a peak which did not in general coincide with the lighting
and traction peaks. Thus relatively little extra capacity was needed to
meet rising power sales. However from 1911 onwards the rising power load
did require considerable additions to capacity. The lighting load was
also beginning to rise again.

Several committees sat during the 1914-18 war to consider
the state of the electricity supply industry. By then its deficiencies
were glaring: too many small units, too much variety of practice. But
many of the faults were already appearing in the boom of 1896-1903.
After 1903 matters got worse because, as is shown in Table 23, there was
no increase in concentration. Even by 1903 there were unexploited
economies of scale. After that existing undertakings simply expanded
piecemeal. Except on the North East Coast there was no tendency to

   Electrical Trades Committee. C&IL. 9072, 1918.
   Williamson Committee. C&IL. 9062, 1918.
   Birchenough Committee. C&IL. 93, 1919.
centralisation. The power companies, who might have achieved this, were not a success. Existing suppliers could or would not co-operate with each other. This lack of co-operation was very wasteful. The extent of economies of scale will be discussed in the next chapter. However one of the major disadvantages of non-co-operation was the very large amount of reserve plant needed. Table 24 shows that only 60% of plant was needed on the average to meet the peak demand. Some plant was clearly intended to meet increases of demand, but not as much as the remaining 40%.

Table 23.

Electricity Supply. Percentage of capacity in the largest ten undertakings.

<table>
<thead>
<tr>
<th>Year</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1896</td>
<td>48.5</td>
</tr>
<tr>
<td>1898</td>
<td>38.1</td>
</tr>
<tr>
<td>1900</td>
<td>33.5</td>
</tr>
<tr>
<td>1902</td>
<td>31.2</td>
</tr>
<tr>
<td>1904</td>
<td>28.0</td>
</tr>
<tr>
<td>1906</td>
<td>27.5</td>
</tr>
<tr>
<td>1908</td>
<td>29.9</td>
</tr>
<tr>
<td>1910</td>
<td>29.8</td>
</tr>
<tr>
<td>1912</td>
<td>28.9</td>
</tr>
</tbody>
</table>

Source: Calculations from Garke's Manual.

1. See Chapter 4.
2. See Chapter 9.
Table 24.

Maximum load as a percentage of central station capacity.

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of undertaking in sample</th>
<th>Aggregate maximum load as percentage of aggregate capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1907</td>
<td>277</td>
<td>57.5</td>
</tr>
<tr>
<td>1909</td>
<td>276</td>
<td>60.9</td>
</tr>
<tr>
<td>1911</td>
<td>283</td>
<td>63.6</td>
</tr>
<tr>
<td>1913</td>
<td>284</td>
<td>61.8</td>
</tr>
</tbody>
</table>


It is important not to overestimate the importance of central station supply. Table 24 suggests that in 1907 and 1912 only 40% of the electricity used for traction lighting and power came from central stations.
Table 25.
The use of electricity 1907 and 1912. m. KWh.

**1907**

<table>
<thead>
<tr>
<th>Generated by user</th>
<th>Traction</th>
<th>Power</th>
<th>Lighting</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generated by user</td>
<td>421</td>
<td>1008</td>
<td></td>
<td>1429</td>
</tr>
<tr>
<td>Purchased from electricity supply stations</td>
<td>224</td>
<td>316</td>
<td>416</td>
<td>956</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>646</strong></td>
<td></td>
<td></td>
<td><strong>2385</strong></td>
</tr>
</tbody>
</table>

**1912**

<table>
<thead>
<tr>
<th>Generated by user</th>
<th>Traction</th>
<th>Power</th>
<th>Lighting</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generated by user</td>
<td>562</td>
<td>1950</td>
<td></td>
<td>2512</td>
</tr>
<tr>
<td>Purchased from electricity supply stations</td>
<td>277</td>
<td>844</td>
<td>507</td>
<td>1629</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>839</strong></td>
<td></td>
<td></td>
<td><strong>4140</strong></td>
</tr>
</tbody>
</table>

1. Power was almost certainly more than 3/4 of this total. Electric lighting was not used as much industrially as in shops, offices and houses, which bought electricity from public supply stations.

For details of calculations see Appendix. Figures have been rounded after calculations.

Sources: Census of Productions 1907 and 1912.
Board of Trade Returns relating to tramways.
" " " " " electric railways.
Appendix.

The Costs of Electricity Supply.

A large amount of information was published about the costs of electricity supply during this period. Unfortunately most of it is either deficient or misleading. Good figures of capital costs, a large proportion of total costs, were rarely given. Running cost figures are given as costs per unit sold (or generated). Because many running costs, labour management, and even some coal costs, were determined by the size of the central station rather than by the number of units generated average cost figures have little economic value.

To analyse precisely the costs of electricity supply and point to changes in cost over the period would be a very large task and has not been attempted. All this section attempts is to shed a little light on the matter.

The costs of electricity supply are of three types. Firstly there are costs incurred by meeting the peak demand i.e. the costs of central station capacity, and most of the cost of the distribution network. Secondly there are the costs incurred by particular consumers, in particular locations, part of the distribution network. Thirdly there are the costs incurred by supplying off peak units. There is no information on the costs incurred by the geographical position of particular consumers. Thus we are left with capacity costs and off peak generating costs; long run and short run marginal costs respectively.

The major component of long run marginal cost seems to have been

capital cost. To arrive at capital cost we must first try and get figures of initial cost per KW of capacity and secondly rates of interest and depreciation. There are two sources for initial cost per KW; engineering estimates and the marginal cost per KW added figure which can be derived from my estimates of gross investment in, and capacity added to, British Central stations. Both are subject to difficulties. The first, which applies particularly to engineering estimates is that there was no accepted definition of capacity. Capacity of generating sets was the measure of capacity usually adopted, but as H.M. Hobart pointed out, generating capacity figures were vague because there was no widely adopted standard of temperature rise and overload. Engineering estimates clearly had a wide variance, but there are not enough of them for one to be able to estimate, and thus allow for, this variance. The marginal cost per KW added figure has the advantage that it refers to average practice. The main disadvantage is that it fluctuates considerably from year to year. This is partly because of inadequacies in the capital expenditure and capacity figures, partly because the variance of the £ per KW statistic was high in practice. To try and deal with this, three year moving averages were taken of the investment and additions to capacity series and the £ per KW figure derived from these moving averages. The results are shown in Table 26.

The generating station was only part of this cost. Often undertakings gave details of capital expenditure on various parts of the

Table 26.

<table>
<thead>
<tr>
<th>Year</th>
<th>Per KW added</th>
</tr>
</thead>
<tbody>
<tr>
<td>1898</td>
<td>93.0</td>
</tr>
<tr>
<td>1900</td>
<td>71.2</td>
</tr>
<tr>
<td>1902</td>
<td>76.6</td>
</tr>
<tr>
<td>1903</td>
<td>75.8</td>
</tr>
<tr>
<td>1904</td>
<td>71.9</td>
</tr>
<tr>
<td>1905</td>
<td>53.6</td>
</tr>
<tr>
<td>1906</td>
<td>45.6</td>
</tr>
<tr>
<td>1907</td>
<td>42.2</td>
</tr>
<tr>
<td>1909</td>
<td>18.4</td>
</tr>
<tr>
<td>1910</td>
<td>36.7</td>
</tr>
<tr>
<td>11</td>
<td>20.6</td>
</tr>
<tr>
<td>12</td>
<td>19.8</td>
</tr>
</tbody>
</table>

supply system. Random samples of 20 were taken for each year, and Table 27 constructed.

More is known about the cost of generating stations, particularly about the costs of generating sets. A certain amount of price data is available on generating sets, but it is difficult to interpret. The cost per KW fell both with bigger machinery, and over time. The generator cost
Table 27.

Electricity Supply. Capital Expenditure.
Percentages on various items.

<table>
<thead>
<tr>
<th>Year</th>
<th>Generating Station</th>
<th>Distribution Network</th>
</tr>
</thead>
<tbody>
<tr>
<td>1896</td>
<td>51.3</td>
<td>43.9</td>
</tr>
<tr>
<td>97</td>
<td>49.7</td>
<td>47.2</td>
</tr>
<tr>
<td>98</td>
<td>56.0</td>
<td>41.5</td>
</tr>
<tr>
<td>99</td>
<td>60.0</td>
<td>37.8</td>
</tr>
<tr>
<td>1900</td>
<td>53.8</td>
<td>43.5</td>
</tr>
<tr>
<td>01</td>
<td>54.4</td>
<td>42.7</td>
</tr>
<tr>
<td>02</td>
<td>56.7</td>
<td>40.7</td>
</tr>
<tr>
<td>03</td>
<td>56.0</td>
<td>41.9</td>
</tr>
<tr>
<td>04</td>
<td>55.8</td>
<td>42.2</td>
</tr>
<tr>
<td>05</td>
<td>55.8</td>
<td>41.3</td>
</tr>
<tr>
<td>06</td>
<td>56.7</td>
<td>39.1</td>
</tr>
<tr>
<td>07</td>
<td>57.2</td>
<td>39.0</td>
</tr>
<tr>
<td>08</td>
<td>52.0</td>
<td>43.7</td>
</tr>
<tr>
<td>09</td>
<td>55.6</td>
<td>42.6</td>
</tr>
<tr>
<td>1910</td>
<td>51.4</td>
<td>43.4</td>
</tr>
<tr>
<td>11</td>
<td>54.0</td>
<td>40.9</td>
</tr>
<tr>
<td>12</td>
<td>50.2</td>
<td>42.0</td>
</tr>
</tbody>
</table>

The remaining percentage was spent on legal charges, Provisional Orders and other miscellaneous matters.

Source: Sampling from accounts in Garke's Manual.
curve seems to have been of the following shape.

Supply stations would tend only to buy plant of optimum size - i.e.,
 somewhere roughly along the horizontal part of the cost curve for any
year. In so far as they did this we can use tender price information
to indicate price changes over time, as is done in Table 28.

But the figures only show the trend crudely.

Perhaps the best indicators of the general shape of part of the
cost curve of generating stations are data given by two eminent engineers
in 1909. Their figures are shown in Table 29.

There were long disputes about what rate to take on initial cost
for capital charges, particularly about the depreciation rate. Writing in
the Electrical Review in 1903 a consulting engineer laid down the following
percentages for depreciation.

<table>
<thead>
<tr>
<th>Item</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buildings</td>
<td>5%</td>
</tr>
<tr>
<td>Plant and machinery</td>
<td>7½</td>
</tr>
<tr>
<td>Mains</td>
<td>7½</td>
</tr>
<tr>
<td>Meters</td>
<td>10</td>
</tr>
<tr>
<td>Instruments</td>
<td>5</td>
</tr>
</tbody>
</table>
Table 28.
Generating Sets. £ per KW

<table>
<thead>
<tr>
<th>Year</th>
<th>£ per KW</th>
<th>Average size of set</th>
<th>Number of contracts</th>
</tr>
</thead>
<tbody>
<tr>
<td>1899</td>
<td>11.6</td>
<td>580</td>
<td>2</td>
</tr>
<tr>
<td>1902</td>
<td>7.1</td>
<td>575</td>
<td>2</td>
</tr>
<tr>
<td>03</td>
<td>9.1</td>
<td>587</td>
<td>3</td>
</tr>
<tr>
<td>04</td>
<td>8.8</td>
<td>1,513</td>
<td>5</td>
</tr>
<tr>
<td>05</td>
<td>5.5</td>
<td>933</td>
<td>3</td>
</tr>
<tr>
<td>06</td>
<td>8.5</td>
<td>1,250</td>
<td>2</td>
</tr>
<tr>
<td>07</td>
<td>6.2</td>
<td>1,250</td>
<td>3</td>
</tr>
<tr>
<td>08</td>
<td>3.0</td>
<td>4,000</td>
<td>2</td>
</tr>
<tr>
<td>09</td>
<td>4.3</td>
<td>1,167</td>
<td>3</td>
</tr>
<tr>
<td>1910</td>
<td>3.9</td>
<td>3,000</td>
<td>1</td>
</tr>
<tr>
<td>11</td>
<td>2.3</td>
<td>1,675</td>
<td>2</td>
</tr>
<tr>
<td>13</td>
<td>2.7</td>
<td>4,853</td>
<td>3</td>
</tr>
</tbody>
</table>

On the whole undertaking he reckoned $5.94. The actual depreciation provision was nearly always at a lower rate. However, $6.0 is almost certainly the minimum real rate of depreciation. Interest rates varied. 4% is probably a reasonable average. Thus capital changes should be at least 10% on initial cost (if the straight line method of depreciation is to be used).

There does not seem to be any satisfactory information on labour and management costs. It could be extracted from accounts, but only with very considerable labour.
Table 29.

Cost per Kw of various sizes of generating stations. 1909.

<table>
<thead>
<tr>
<th>Size of station</th>
<th>1 H.M. Hobart</th>
<th>2 G.L. Addenbrooke</th>
</tr>
</thead>
<tbody>
<tr>
<td>KW</td>
<td>£</td>
<td>£</td>
</tr>
<tr>
<td>1500</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>2500</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>3000</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td>5000</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>6000</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>10000</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>12000</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>20000</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>24000</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>40000</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>48000</td>
<td>14</td>
<td></td>
</tr>
</tbody>
</table>


Coal costs are the principal element in short run marginal costs.

But it was soon noticed that coal costs varied inversely with the load factor and thus one cannot take the average coal cost per unit generated as an approximation to short run marginal cost. Unfortunately hardly any useful records of coal consumption were published. However in a paper given to the I.E.E. in 1907 on Central Station Economics, their study and what it promises in the way of cheaper supply, H.H. Taylor gave coal consumption figures for various amounts of electricity generated in a 3000 kW station in a period of 500 hours. His figures show that fuel consumption is a linear function of the quantity of electricity generated.

For a 500 hour period the following equation can be calculated -

\[ C = 800,000 + 3.28K \]

where \( C \) = Coal consumption in lbs. and \( K \) = KWh generated.

Thus in a 500 hour period the cost of 800,000 lbs. of coal can be regarded as being connected with the size of the generating station rather than the quantity of electricity generated. Taylor's figures were based on the use of coal and slack at 7/6 a ton. At this price the capacity cost of coal is £0.78 p.a. per KW, and the short run marginal (coal) cost 0.132d. per KWh.

Unfortunately similar figures for other years are not available.

We know that fuel costs were higher before 1907 and lower afterwards. But we cannot say by how much.

1. First by J. Hopkinson in a paper to the Junior Engineering Society in 1892.


3. For a later period H.H. Parsons expressed coal consumption as a linear function of electricity generation. His time period was the shift and his equation \( C = 5000 + 1.23K \). (R.H. Parsons, op.cit. Appendix 1.)
As the unknown management and labour costs were very largely capacity costs, at least this appendix will have given some indication of the very great difference between long and short run marginal costs.
Chapter 4.

The power companies sought to utilise economies of scale in electricity generation for two purposes: to supply electricity in bulk to existing electricity suppliers, and new ones, especially in the smaller towns, and to supply electricity for power, both for electric traction and for factories. The conversion of trams to electric traction had been expected during most of the nineties, although it did not start in earnest until 1897, and electric power had begun to be used in the United States from the middle nineties, although the electrification of English factories was very rare until 1900.

The first power scheme was that of the General Power Distribution Company, promoted by a syndicate of large manufacturers in the Chesterfield area. Powers were sought by Act of Parliament for supply over a large area of Derbyshire, Nottinghamshire, Lincolnshire and the West Riding. Over most of the area no one had authority to

1. See Chapter 5.
2. See Chapter 6.
supply electricity but it included the towns of Sheffield and Nottingham, both with municipal supply. The Company wanted to be able to compete with existing suppliers, and principally because of this it was strongly opposed in 1898 by affected municipalities. This caused the Bill to be held over to the next Parliamentary session and in 1899 it was opposed by the Municipal Corporations en bloc, and thus failed at the second reading on the grounds that it upset the present law and was "prejudicial to the privileges of the great municipalities". As a result the Cross Committee was appointed in 1899, which recommended that technical changes had created conditions different from those envisaged by the drafters of the earlier Acts and that it was desirable to give power to undertakings who were to use plant of exceptional dimensions and high voltages, to supply over a large area which included existing suppliers. This report formed the basis for the Electric Power Bills of 1900, 1901 and 1902. In 1900 Bills were passed for power companies in South Wales, Durham, Lancashire (south of the Ribble) and the North Metropolitan area (from Hertford and St. Albans south to Willesden and Stoke Newington.) The Durham and North Metropolitan schemes were for supply to authorised distributors only, and passed without difficulty. The Lancashire and South Wales Bills were very strongly opposed by the big municipalities. They disliked the requests for powers to give power supply to big customers within their areas. As a result the big municipalities were excluded from both schemes, thus cutting out much

of the most profitable areas of supply. This set a precedent and in future Acts the municipalities managed to get themselves excluded if they could show that they were already giving a cheap supply for power.

Table 30.

**List of Electric Power Companies.**

<table>
<thead>
<tr>
<th>Company</th>
<th>Date of initial Act of Parliament</th>
<th>Date of commencement of supply</th>
<th>Capacity of generating stations 1912 KW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Newcastle</td>
<td>1902</td>
<td>1900</td>
<td>90660</td>
</tr>
<tr>
<td>North Metropolitan</td>
<td>1900</td>
<td>1901</td>
<td>15990</td>
</tr>
<tr>
<td>County of Durham</td>
<td>1900</td>
<td>1902</td>
<td>0</td>
</tr>
<tr>
<td>Midland</td>
<td>None</td>
<td>1902</td>
<td>10600</td>
</tr>
<tr>
<td>Derbyshire &amp; Nottinghamshire</td>
<td>1901</td>
<td>1903</td>
<td>5080</td>
</tr>
<tr>
<td>South Wales</td>
<td>1900</td>
<td>1903</td>
<td>17450</td>
</tr>
<tr>
<td>Cleveland and Durham</td>
<td>1901</td>
<td>1904</td>
<td>6000</td>
</tr>
<tr>
<td>Clyde Valley</td>
<td>1901</td>
<td>1905</td>
<td>27300</td>
</tr>
<tr>
<td>Lancashire</td>
<td>1900</td>
<td>1905</td>
<td>18500</td>
</tr>
<tr>
<td>Yorkshire</td>
<td>1901</td>
<td>1905</td>
<td>10000</td>
</tr>
<tr>
<td>Scottish Central</td>
<td>1903</td>
<td>1905</td>
<td>3600</td>
</tr>
<tr>
<td>Fife</td>
<td>1903</td>
<td>1905</td>
<td>7000</td>
</tr>
<tr>
<td>North Wales</td>
<td>1904</td>
<td>1906</td>
<td>6000</td>
</tr>
<tr>
<td>Kent</td>
<td>1903</td>
<td>1907</td>
<td>3500</td>
</tr>
<tr>
<td>Cornwall</td>
<td>1902</td>
<td>1911</td>
<td>2800</td>
</tr>
<tr>
<td>Shropshire, Staffordshire and Worcestershire</td>
<td>1903</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Total 224,480
Table 30 continued:

1. The Midland Electric Corporation for Power Distribution operated under a number of Provisional Orders only.

2. Powers transferred to the Birmingham & Midland Tramways, who already had a power station, in 1903.

3. 1910, later figures not available but 1912 figure would certainly be higher.

4. 1913

5. Included in Newcastle - the two companies were fully integrated.

Table 30 tells its own story. The power companies were not quick off the mark and a comparison with the biggest ten other undertakings (Table 31) shows that by the end of 1912 they had not become very large. There is one exception: the Newcastle Electric Supply Company was extremely successful, ran a unified system together with the County of Durham Power Company, and from 1912 onwards the Cleveland and Durham Company. This local grid extending from the Northumberland coalfield to the Cleveland ironfield had much more generating capacity than any other undertaking. In 1912 it had about 42% of the total capacity of all the British power companies.

Table 31.

Some other big undertakings in 1912.

<table>
<thead>
<tr>
<th>Undertaking</th>
<th>Capacity of generators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manchester Corporation</td>
<td>59,300</td>
</tr>
<tr>
<td>Glasgow Corporation</td>
<td>41,030</td>
</tr>
<tr>
<td>Birmingham Corporation</td>
<td>37,465</td>
</tr>
<tr>
<td>Liverpool Corporation</td>
<td>37,000</td>
</tr>
<tr>
<td>Sheffield Corporation</td>
<td>28,500</td>
</tr>
<tr>
<td>London E.S. Corporation</td>
<td>27,250</td>
</tr>
<tr>
<td>City of London E.S. Co.</td>
<td>25,000</td>
</tr>
<tr>
<td>Metropolitan E.S. Co.</td>
<td>23,250</td>
</tr>
<tr>
<td>Leeds Corporation</td>
<td>22,940</td>
</tr>
<tr>
<td>County of London Company</td>
<td>20,300</td>
</tr>
</tbody>
</table>

Total 322,035

1. Estimated.

If we exclude the North East Coast Companies, the average power company in 1912 had only about 10700 kW capacity. As the standard large turbo alternator being installed was about 5000 kW, many of them could claim few of the economies of scale which were to justify their existence. Except in the North East the power companies became suppliers to the smaller settlements outside the areas of the large municipalities. Some, like the Clyde Valley, Lancashire and Yorkshire schemes specialised in power supply, some like the North Metropolitan and the Midland were general all round suppliers.

Except for Newcastle those specialising in power were not financially successful. The worst case is that of the South Wales Company. By 1904 it had built four power stations, only one of them being large, but was unable to raise further capital. By June 1906 the situation had become so bad that the Company had to make arrangements with its consumers to provide capital to continue operations. The two smaller generating stations were sold to the relevant local authorities. The Treforest Electrical Consumers Company was formed to work one area and provided £30,000 for generating plant. The power company was reconstructed and continued to work one part of its area.

There are a number of reasons for the poor showing of the power companies. Except for Newcastle, the big towns were cut out from the beginning. Glasgow the heart of Clydeside was in the hands of Glasgow Corporation, the Lancashire and Yorkshire power companies threaded their trunk mains between the big towns. Lighting loads outside the big towns were expensive to supply as outside areas of high population density
Cable costs per lamp were high. Tramways were chiefly located in the big towns and where they took public supply they generally bought it from the town power station. Power supply for industry was slow to develop. This was partly because the electrification of factories did not really start on more than a very small scale until about 1905. Electric driving for textiles came late largely for technical reasons, and the colliery owners were conservative; the Lancashire, Yorkshire, Clyde Valley and S. Wales Companies were in textile and mining areas. It was also partly because it was often better to put down an "isolated" installation rather than take public supply. Again many potential power consumers were inside the big towns.

The power companies found it very difficult to borrow, especially for their big schemes. The gestation period of investment was long and big schemes would naturally operate at a loss in the early years. Costs were often underestimated. The down turn of the trade cycle came before enough had been raised, and the heavy foreign investment from 1904 onwards made the raising of money for home investment difficult. The costs of a private Act of Parliament were high and severely handicapped the companies in their early days. The matters mentioned in the last paragraph naturally made borrowing more difficult.

Apart from demand and financing difficulties, there is reason to suppose that the engineering of some of the schemes was not very good. And engineering ability of a high order was necessary to make them a success.
Table 32.
The Power Companies in 1905.

<table>
<thead>
<tr>
<th>Company</th>
<th>Number of power stations initially planned</th>
<th>In Operation</th>
<th>Aggregate capacity in operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cleveland and Durham</td>
<td>7</td>
<td>3</td>
<td>4,750</td>
</tr>
<tr>
<td>Clyde Valley</td>
<td>3</td>
<td>2</td>
<td>8,000</td>
</tr>
<tr>
<td>Derbyshire &amp; Nottinghamshire</td>
<td>4</td>
<td>1</td>
<td>720</td>
</tr>
<tr>
<td>Lancashire</td>
<td>4</td>
<td>1</td>
<td>6,000</td>
</tr>
<tr>
<td>Midland</td>
<td></td>
<td>1</td>
<td>3,100</td>
</tr>
<tr>
<td>Fife</td>
<td></td>
<td>1</td>
<td>800</td>
</tr>
<tr>
<td>S. Wales</td>
<td>3</td>
<td>4</td>
<td>7,640</td>
</tr>
<tr>
<td>Yorkshire</td>
<td>4</td>
<td>1</td>
<td>6,000</td>
</tr>
</tbody>
</table>

* This was a pilot scheme, opened in 1905. But 1905 was extremely late for a pilot scheme.

The Bramwell and Harris schemes, the Cleveland and Durham, the South Wales and the Derbyshire and Nottinghamshire were poorly engineered, with small stations and small plant. The Lancashire, Yorkshire and North Metropolitan were also planned with several small stations, although the former two were replanned under H.P. Parshall, an American who had come to England in the late 1890s to deal with the B.T.-H. tramway building. The big municipalities

1. The Consulting Engineers.
usually opposed the power companies partly on the grounds that they could supply at least as cheaply themselves. In the years 1900-05 when these power schemes were planned, the evidence is very largely on their side, their engineering seems to have been at least as good, and their costs lower than those of the power companies, because of their more favourable geographical position.

The Newcastle scheme had none of these disadvantages. It grew out of an existing undertaking which made financing easier; there was no initial long waiting period before dividends were paid. Once successful it could continue to raise money. The local government situation on Tyneside was very favourable. Newcastle Corporation had not been interested in electricity supply, and the rest of the north bank of the Tyne was composed of small local government areas. There was a dense industrial area to be served, with very progressive engineering factories. Even before the Newcastle power scheme Tyneside had been noted for its factory electrification. Shipbuilding was booming and progressive and there were close links between important industrialists and the Newcastle Electric Supply Co. In 1904 the North Eastern Railway opened the first electrified suburban lines in this country. To start the scheme there was Charles

1. Henceforth referred to as N.E.S. Co.

2. The Lancashire and Yorkshire Railway opened its electrified Liverpool-Southport line in the same year and thus shares the North Eastern's position as a pioneer of main line railway electrification.
Merz, who had exactly the right combination of vision, optimism and technical skill. From the beginning his engineering was admirable and the construction of Carville power station, opened in 1904, was one of the big landmarks in electricity supply.

The Newcastle power scheme started with the plans of J. Wigham Richardson, the Tyne shipbuilder. He was impressed by the use of electric power in shipbuilding as were other Tyneside marine engineers. He was also a director of the Wallsend and Walker Gas Company, which had been a pioneer in the use of gas for industrial purposes. He persuaded the gas company to begin electric supply and in 1898 a scheme was in preparation. Wigham Richardson’s brother-in-law and fellow Quaker was J.T. Merz, a director of N.E.S. Co.

1. Merz’s Private Notes have been an important source of information for the rest of this chapter. Merz was born in 1874. Educated at Bootham School, York. In 1891 he spent a year at the Durham College of Science. In 1892 he joined N.E.S. Co. as an apprentice. In 1894 he joined B.T.H. In 1899 he became a consulting engineer, forming the partnership of Merz & Lecellan. See J. Rowland, Progress in Power privately printed 1950 for the story of Merz & Lecellan.


They had also had business associations in the years around 1870.

In 1898 Charles, Merz's son, who had at the age of 24 quite considerable engineering experience both in power stations and with the British Thomson-Houston Company, was asked to help with the preparation of the Act of Parliament for the Walker and Wallsend scheme. He was very critical of the gas company's consulting engineer and made him modify the scheme. With Merz's help the Bill soon passed. Then he was appointed consulting engineer to the company. The foundation of his scheme was the 3 phase motor, virtually unknown in the country at the time. Merz knew of its value through his associations with the Americans at B.T.-H., and had made his own experiments with it. He was determined to use it as he was sure it was the best motor for the shipyards. He also visualised electric traction and wanted to be able to supply lighting as well. At the time it was technically difficult to amalgamate the three because lighting and power worked best at different frequencies. No English manufacturers were interested in 3 phase machinery and Merz discussed

1. Merz had very successfully managed the Blyth Chemical Works for Richardson, who had invested a considerable amount of money in them. Richardson felt indebted to Merz and this seems to have been one reason why he thought of helping Charles Merz by asking him to investigate the Walker and Wallsend electric power scheme. The latter was only a very young man although he must have showed signs of great ability. (See Private Notes of C.H. Merz, unpublished; Memoirs of J. Wigham Richardson, privately printed, Glasgow 1911).

2. Rotary convertors for converting 3 phase a.c. to d.c. for traction were usually run at 25.\(\nu\). Lights flickered noticeably at as low a frequency as this.
the matter with General Electric and Brown-Boveri. There was no obvious solution but eventually it was decided to adopt 40 cycles per second as a compromise. It worked very well. This was an important capital saving innovation, as less power station plant and also much less transmission and distribution plant was needed.

N.E.S. Co. were also interested in power supply and in 1893 they had installed two 500 kW d.c. generators in addition to their lighting alternators for supplying motive power in Newcastle. Merz when planning the Walker and Wallsend scheme had devoted a good deal of effort to getting customers. He had had long discussions with various engineers and shipbuilders about the value and cost of electric power. Thus both the Merz and Wigham Richardson decided to promote a power Act to link up N.E.S. Co. with the Walker and Wallsend scheme and to sell power along most of the north bank of the Tyne. At the same time Parsons, Campbell Swinton and others were promoting a rival power Act for the whole of Tyneside. Parsons was a director of the Newcastle and District Electric Supply Co. which supplied the western half of Newcastle. This latter was a larger scheme and had very influential promoters but the Merz and Richardson had the advantage of having already started on their scheme and could point to their partially constructed power station at Neptune Bank adjacent to the

1. The Americans used 25 cycles for traction and 60 cycles for lighting and power. The Swiss used 40 cycles and 50 cycles.

2. Other parts of the country later standardised at 50 cycles and after the 1926 Electricity Supply Act the North East system was converted to that frequency.
big shipyards. They won. In June 1901 Lord Kelvin opened Neptune Bank which provided the first 3 phase public supply in this country. At first it catered for a few big shipyards, but the success of electric power led to considerable extension. By 1905 it was able to tell a Select Committee of the House of Lords both that "all the private plants on the North Bank of the Tyne have either been done away with, or are being done away with" and that on Tyneside in the H.E.S.Co. areas one-half to two-thirds of the total power used is supplied by H.E.S. Co. The supply area was soon extended northwards by the passage of an Act in 1902 to include the Northumberland coalfield. This was also opposed. The Northern Counties Electric Supply Co. which had a number of small power stations in Northumberland and Durham, wanted authority for its own power scheme in Northumberland. H.E.S. Co. won because of its careful estimation of demand, its excellent record of technical skill and good management revealed in its very low costs, and the way in which it anticipated demand in its investment planning. Electric power for collieries was, however, slow to develop and more important for the company was the beginning of its traction supply. In 1902 H.E.S. Co. and others promoted the Tyneside Tramways Bill for electric tramway

1. Select Committee of the House of Lords on the Administrative County of London and District Electric Power Bill, Q 7.
2. ibid., 9. 1210.
powers on the north bank of the Tyne east and north east of Newcastle.

The proposal was opposed by the North Eastern Railway who feared competition on their Newcastle to Tynemouth line. During the course of the proceedings Mars suggested to George Gibb, the Chairman of the N.E.R., that for the railway to electrify its suburban lines north of the Tyne was the best answer to tramway competition. Gibb who was clearly much impressed by Mars got him to write a report for the Railway on electrification and in August 1902 Mars issued specifications for the electrification of 62 miles of single track and invited tenders.

In February 1903 N.E.S. Co. signed a very favourable agreement with the North Eastern Railway. Power was to be supplied by the Supply Company who were to build a new power station and guarantee the railway company 4000 kW of its capacity. The mains and substations were to be built and equipped by the railway company and rented to the supply company who were to maintain them and pay a rent of 5½ p.a. on cost. A most important clause enabled the supply company to use the cables and substations for supply to other consumers. They would pay for extra plant but gained considerably from the fact that the cables installed were of a capacity much in excess of that required by the railway company. The company probably spent something of the order of

1. There is a story still in circulation that the Newcastle Electric Supply Co. helped to finance the Tyneside Tramways to induce the North Eastern Railway to electrify.
£90,000 on this distribution system. It is not known how much of this was necessary simply for supplying the railway but the magnitude of the money raised in this way through the railway company can be seen by the fact that by December 1904 the supply company had spent £256,000 on high tension cables and sub stations, and £1,229,000 on everything excluding the Newcastle city installation dating from 1890. The agreement with the North Eastern Railway Co. thus contributed to N.E.S. Co.'s very rapid expansion at the time on both the demand and the supply sides. Meanwhile N.E.S. Co. had started to give a bulk supply to the 2 County of Durham Electric Power Company. The latter had powers for supply to authorised distributors in the Northern half of County Durham, including the south bank of the Tyne. It was owned by the British Electric Traction Company, who had used it only for supply to their trams in Gateshead, Jarrow, and Durham City where they also held provisional orders. In 1904 the Durham Company was taken over by N.E.S. Co. and the area began to be developed. The latter was determined to supply to the county generally, especially the collieries, 1. If the railway company reverted to steam the supply company was to purchase the cables etc. at cost, not exceeding £90,000 less 4% p.a. depreciation - or at the option of the railway to pay 5% rent in perpetuity.

2. Parliamentary powers were obtained in 1902.

3. The County of Durham Electric Power Company, which held the Parliamentary powers was owned by the County of Durham Electric Power Distribution Company which held the provisional order.

4. N.E.S. Co. and the Durham Companies were run as one unit from 1 January 1905.
and not merely the larger towns.

In 1904 traction supply made up the bulk of sales. The combined sales of the Newcastle and Durham Companies were approximately 17.4 million KWh; 9.6 million went for traction, 5 million to manufacturers chiefly on the Tyne and the rest for lighting. This concentration in traction was typical of big undertakings: Manchester in 1904 sold 33.7 million KWh of which 18.9 million were for the Corporation Tramways.

The rapid rise in output from under a million KWh in 1899 to over 17 million in 1904 was more than the Neptune Bank power station could deal with and in 1904 the new Carville power station, which had been started when the electrification of the North Eastern Railway was planned, was opened. Carville, designed by Merz, was a major break through in power station design, the beginning of what eventually became standard practice. What Merz arrived at was a big improvement in the reliability of plant and a big reduction in costs. And costs could best be reduced by reducing the initial cost of the power station. Both were to be achieved by a radical reorganisation and simplification and the use of plant incorporating the best engineering practice.

1. The biggest town in the area, Sunderland, had a very progressive and efficient municipal supply, managed at the time by J.F.C. (later Sir John) Shill, and would have been extremely unlikely to take a bulk supply.

2. In Newcastle, the tramways were eventually electrified and run by the Corporation from their own power station.

3. See C.H. Merz and W. McLellan, Power Station Design. Paper read to the I.E.S., 23 April 1904. This paper was years in advance of other contemporary writing on power stations. It is thus all the more remarkable that Merz was simply preaching what he had already practised at Carville.
"The commercial success of such an undertaking (for power supply) is absolutely dependent upon the cheapness and reliability of supply. It may be argued that this is no new phase of the supply problem; but the argument, though possibly correct in principle, is so wide of the mark in degree that is a station for power supply were designed on similar lines to many existing power stations for traction and lighting purposes commercial failure would almost certainly result."

Capital costs, Merz argued, were much too high; when boiler plant was obtainable for £2 - 3 per KW and generating machinery for £10 per KW at the outside, it was surprising to find power stations coming out with a total cost of £40 or even more per KW. To reduce capital costs was of overwhelming importance, and with good initial design this could easily be done. Like the principles behind all major innovations, this now seems obviously correct. But Merz's principles cut right across current power station practice. Perusal of the technical literature of the time does reveal very much more concern with running costs, particularly coal costs, than with capital costs, although capital costs accounted for at least half of the total costs of supply and coal costs for less than a quarter. In the design of plant simplicity had been sacrificed to elaborate complications to avoid an interruption of supply. Merz had to stress the principle that no complications should be introduced to facilitate the repair of a breakdown should the complications increase materially the risk of breakdown.

"That all the earlier station engineers should consistently disregard this axiom was perfectly natural, as in view of the comparatively unreliable apparatus at their disposal they were more impressed by the necessity of speedy repair than by the importance of avoiding a breakdown altogether. In fact they came to regard breakdowns as inevitable, devoting their attention to minimising their effect rather than to reducing the amount of apparatus in which a breakdown could occur.

1. Merz and McEllan, op.cit.,
This line of procedure, while possibly justifiable in the earlier stages of the industry, has in many cases been pushed too far. In some stations the designers have apparently set themselves the task of rendering possible every conceivable combination of boiler and engine, engine and exciter, pump and boiler, etc.¹

They recommended the "unit" system of construction, whereby the plant was divided into several independent units - each consisting of boilers, engines, dynamos and switchgear. This was essential to reliability.

"If trouble was to be had with anything it would be obtained by crowding together all kinds of water and steam pipes; if trouble was to be had with switchgear it would be obtained by fixing many cables or connections for different purposes either on one panel, or in one partition, or in one cable trench ...."

Power Stations must be designed so that they could be inexpensively extended.

"It is possible in laying out a station to avoid placing chimneys, flues, offices and elaborately built brick ends so as to interfere with extensions to either boiler houses or engine rooms, although it is to be feared that this is not always done"²

They advocated a steel framed building, where the filling between the columns was merely a weatherproof screen wall, a contrast to the solid brick structures of current practice. This type of construction represented an innovation in building. As Merz told a Select Committee of the House of Lords in 1905, "You look on the boiler house of a modern electric station in much the same way as you look on the boiler house of a ship, where the structural part and the machinery are very much

intermingled and form part the one of the other." Steel frame buildings were rare in those days although some had been built in Chicago from the 1880s.

Carville used only steam turbines, the first big English power station to do so. One 1500 KW Parsons turbine had been installed at Neptune Bank, at Wigan Richardson's suggestion, and had worked very well. The turbine, as stated earlier, was capital saving; the cost of buildings was much reduced by using it, and it had a high overload capacity. Morz pointed out what was usually neglected, that it was economically desirable to use this overload capacity to meet the normal peak, and not just for sudden emergencies, that higher running costs would be considerably over-compensated by reduced capital costs. He considered that capital costs could be reduced by 20 - 40% by a careful consideration of the shape of the load, overload capacities and spare plant.

In 1904, Morz was 30, but all this is not simply a young man's criticism of current practice. The average power station at the time cost a little over £4.0 per KW. Big stations were cheaper. Manchester's Stuart Street station, opened in 1902, cost £24.5 per KW excluding land. West Ham's station, which was a contemporary of Carville, £25.6 including land. Engineers estimates of proposed large power stations in 1900 - 03

2. Sec Appendix on Power station costs.
3. Select Committee on Administrative County of London Bill 1905. Q. 4579-83. Answers of A.B.W. Kennedy, designer of the Stuart Street Station.
4. ibid., Vol. 3, P 661.
varied between £20 and £25 per KW, but the usual tendency in such estimates was to underestimate costs. In 1902 Merz predicted that Carville would cost £18.7 per KW; the completed cost was £16.3 per KW of normal capacity. Fuel costs were low at Carville, partly because coal was cheap on the Tyne, partly because the power station was built on the river with good coal handling and condensing facilities, and also because despite its low cost the Carville generating machinery had as low a coal consumption as any, and much lower than most.

With Carville as the lowest cost power station in the country the Newcastle system soon grew north and south. In 1905 22,000 v. cables, using the highest voltage in Britain, were laid into Durham. Power supply developed rapidly and in 1907 output had risen to 100 million KWh, of which approximately 77 million were for power supply (excluding traction.) This was 24% of the total sales of electricity for power by public supply stations in 1907, and the Newcastle Electric Supply Co.'s power sales

2. Select Committee on Administrative County of London and District Electric Power Bill, 1905. Q. 569.
3. Carville was designed with a 36% overload capacity.
4. Data from the Newcastle Electric Supply Co. historical statistics. Sales for power supply are my estimates.
5. Table 22.
alone were greater than the total sales of any other electric supply undertaking.

The Durham Collieries Electric Power Company was formed in 1905 to supply collieries in north Durham. A power station was built but the company was soon in financial difficulties and in 1907 N.E.S. Co. underwrote its debentures and took over the operation of its power station. Its subsidiary, the Houghton-le-Spring Company, bought current in bulk from it, supplying mainly to collieries, and N.E.S. Co. began to operate this distribution system as well from the beginning of 1909.

From 1907 onwards N.E.S. Co. became interested in the Cleveland and Durham Company. Lazard Brothers, the Paris issuing house, which in 1906 had arranged the first issue of the Newcastle Electric Supply Co. shares outside the North East, asked Merz to investigate it. It had been badly engineered and much of the initial investment was misdirected. By 1907 it had insufficient capital for proper development and in order to assist, Merz helped to form the Waste Heat Company. The idea was that owners of blast furnaces and coke ovens should co-operate in erecting generating stations to use waste heat and gas. Some of the electricity would be used by the coke oven or furnace and some sold to the supply company. The idea had started with Blaydon Power Station which had come into operation in 1904. N.E.S. Co. and the Priestman Colliery Company had together formed the Priestman power

1. Manchester, the second largest undertaking, sold 63 million KWh in 1907.

2. C.H. Merz, Private Notes; and R.P. Sloan, Evidence to Coal Conservation Commission in 1917.
company each subscribing half the capital for the power station. Waste
gas from coke production was used to drive a 2000 kW Parsons turbine,
electricity being fed into the N.E.S. Co. grid when gas was available.
Elsewhere exhaust steam was utilised through exhaust turbines. The
West Heat Company's power stations fulfilled the same purpose, most of
the capital in this case being provided by the Cleveland Company.
N.E.S. Co. and the Cleveland Company drew more closely together and in
1909 the two systems were inter-connected. In that year the two
companies obtained very extensive parliamentary powers for linking up
generating stations, transferring mains, and making agreements on new
works. This marks the beginning of the first area grid which stretched
from north of the Tyne to South of the Tees. As the Cleveland Company
grew it began to buy electricity from the low cost Newcastle stations
rather than extend its own plant. In 1912 it bought 12 million KWh,
in 1914 21 million. In 1914 N.E.S. Co. bought a controlling share of
the Cleveland Company's shares.

The other electricity suppliers in the area were the Northern
Counties Electric Supply Company, the Newcastle & District Co., and the

1. A turbine which used steam at atmospheric pressure, discharging it
   at a high vacuum.

2. P.B. Henderson, op.cit., P 73.

3. The connection was made on 26 June 1909 and thus two stations
   45 miles apart were run in parallel. Newcastle Electric
municipalities. The Northern Counties Company owned a number of small generating stations and provisional orders scattered over Northumberland, Durham and North Yorkshire. In 1906 it became linked with the Cleveland and Durham company, which provided it with bulk supply for distribution within the Cleveland Company's area. In 1912 N.E.S. Co. took over control of the Northern Counties Company's operations in the N.E.S. Co.'s area and thus it was integrated into the N.E.S. Co. grid. The Newcastle & District Co. remained separate and the Corporations of Darlington, Middlesbrough, South Shields, Stockton, Sunderland, Tynemouth and West Hartlepool had their own generating stations. In 1906 however Middlesbrough and Tynemouth decided to start buying current in bulk rather than extend their generating capacity, and they were soon followed by Stockton. The others remained entirely separate until much later.

Thus before 1914 there was a large local "grid" in the North East. The interconnecting of stations meant that the newest and most efficient stations could be used for the base load and older smaller ones used for the system peaks, thus substantially reducing generating costs.

1. A holding company Cleveland and Durham Electric Power Ltd., was formed to control both the Cleveland & Durham Electric Power Company (which hold the Parliamentary powers) and the Northern Counties Company.
2. P.D. Hendraon, op.cit., PP 81 & 83.
Carville from 1908 onwards had an average load factor of 50%, which was an important reason why its costs were so low. From 1905 Neptune Bank became less used and from 1907 was only run to meet the peak. Similarly Hoscum power station, planned as the County of Durham Power Company's main station was only used for peak loads. Also the interconnection of customers over a large area, and over a wide range of industries, led to considerable diversity of peak loads. In the years 1904 - 1910 inclusive the maximum simultaneous load on the N.E.S. Co. generating stations was on the average only 88% of the sum of the maximum loads on each station. But in those years Carville dominated N.E.S. Co.'s power stations, accounting for 64% of the system capacity on the average in 1906 - 10. And by the time Carville reached its ultimate capacity of 39,000 kW by 1909 it was the second biggest power station in Britain and in fact had more capacity than any other supply undertaking except Manchester which had 3 power stations. Thus the diversity of loads achieved because of the size of the N.E.S. Co.'s undertaking is much underestimated by the above figures. Merz attributed a large

1. Average of the load factor 1903 - 1914 inclusive. It is exceptionally high for a pre-1914 power station.

2. Later figures not available. 1907 is missing.

3. Cleveland and Durham Company not included.

4. The Lots Road Power Station of the London Underground Railways was the biggest with 44,000 kW.
part of the very high load factor of the system, which was between 40
and 50\% from 1907 onwards, to the diversity of loads.

But costs were also low because of continued excellent
engineering. In 1905 - 09 23000 kW of capacity were added at Carville
at an average cost of £9.8 per kW. A new station was opened at Dunston
in 1910 with 23000 KW of plant, at a capital cost of £10.5 per KW.
This was very much lower than the national average.

Table 33.

<table>
<thead>
<tr>
<th>Year</th>
<th>Lighting</th>
<th>Heating</th>
<th>Traction</th>
<th>Power</th>
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<tr>
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<td>Small</td>
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<td>Collieries</td>
<td>Chemical</td>
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<td></td>
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<td>factors</td>
<td>Process</td>
<td>Process</td>
<td>Bulk</td>
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<td>3.5</td>
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<td>11.6</td>
<td>1.1</td>
</tr>
<tr>
<td>07</td>
<td>4.5</td>
<td>0.4</td>
<td>13.3</td>
<td>1.6</td>
</tr>
<tr>
<td>09</td>
<td>4.5</td>
<td>0.5</td>
<td>11.2</td>
<td>1.6</td>
</tr>
<tr>
<td>1911</td>
<td>5.2</td>
<td>0.7</td>
<td>15.5</td>
<td>1.9</td>
</tr>
<tr>
<td>13</td>
<td>6.3</td>
<td>1.1</td>
<td>15.3</td>
<td>2.5</td>
</tr>
</tbody>
</table>

1. The Newcastle Electric Supply Co. statistics are ambiguous, but from
1908 onwards the load factor seems to have averaged about 45\%.

2. Includes Durham Companies, Durham Collieries Co. and Northern Counties Co.
   (after 1911)

3. Bulk supply to Northern Counties Co. before 1912, Cleveland and
   Durham Co. and Tynemouth Corporation.

4. All estimates, except Traction in 1905, and Chemical and Process.

Source: Calculations from the Newcastle Electric Supply Co.
Historical Statistics.
In 1905 a Bill was promoted to try and reorganise London's electricity supply on Tyneside lines. Existing supply was given in the west by the companies founded around 1890, and in the east by the Borough Councils. The companies had built bigger stations around 1900 and in two cases companies had combined to build and run joint generating stations. But by 1904 it was clear that a good case could be made out for considerable centralisation. The area allotted to each company and local authority was small, different undertakings supplied adjacent streets and the optimum size of generating station was constantly increasing. Centralisation could have taken place either by further joint generating stations and closer co-operation between existing suppliers or the establishment of a new undertaking. The latter's powers could have ranged from a complete monopoly to co-ordinating the generation of existing undertakings and linking them together.

West London was supplied by companies and they had by 1905 plans for some co-ordination. But there was no great enthusiasm on their part. One would not expect much from the nature of the market. They had primarily lighting loads, and thus an inelastic demand for their product. Only a substantial reduction of costs would have made a rapid expansion of output profitable. To combine at existing levels of output would have yielded small results, as existing plant had a low market value, and would not have been likely to produce a worthwhile return on the cost of the

1. The demand for electric lighting was increasing; a rapid increase in output means a more rapid increase than this.
Parliamentary powers. The latter would have been very difficult to get and thus expensive. The local authorities in the East End were anxious to sell electricity for motive power, which the companies were generally not. But they regarded themselves as quite big enough to take advantage of all economies of scale. C.H. Worsingham argued that the Borough power stations on the river were as economical as one could expect any to be.

The two chief contenders for a new centralised scheme were the L.C.C. and the Administrative County of London and District Electric Power Company. The L.C.C. had recently started to electrify London's tram, but its slowness in doing this, and its obsolete engineering when it came to do it, does not make one feel it would have managed such a scheme very well. Its 1905 Bill failed to pass the Parliamentary Committee because in the opinion of the Board of Trade it did not ensure cheap supply, when at the same time the Council's Finance Committee thought it unlikely to give a satisfactory return to the ratepayers. Its 1906 Bill was rejected by the Parliamentary Committee as similarly inadequate despite the fact that 6 of 9 members of the Committee were either Liberal or Labour, and it considered in general both that a centralised scheme was the best thing for London electricity and that the L.C.C.

1. See Chapter 3, p. 113.
2. See Chapter 5.
should carry it out.

There were several company schemes, the East London and Lower Thames Bill of 1904 and several in 1905 by the existing suppliers, but the one which nearly succeeded and the only one of all of them which was radical enough in technology to succeed in practice was Merz's, that of the Administrative County of London Company.

Merz's plans were based on an increase in output resulting from the development of a power load. In 1905 in the relevant area there were 39 undertakings with an aggregate capacity of 201,706 KW. Merz proposed three new power stations with an aggregate capacity of 210,000 KW. In the two big stations - each of 90,000 KW - he was to put 10,000 KW turbo-alternators, each unit thus being nearly twice the average size of existing undertakings. No generating units of such an output had ever been constructed, although marine turbines larger in size but not in output had been built by Parsons, and on the Continent Brown-Boveri had built turbo alternators of 7000 KW. In England there was nothing bigger than the rather unsatisfactory 5500 KW turbines of the London Underground Railways. But Merz, Parsons and C.E.L. Brown claimed that by building 10,000 KW-turbo alternators when the largest machines being installed at the time were of about 3,000 KW, the cost of generating units per KW could be reduced by at least 20%.

2. Select Committee of the House of Lords on the Administrative County of London and District Electric Power Bill. 1905. Qs 1852-5.
3. Ibid. Qs 1888, 2005.
Generators would reduce other capital costs and with good design Merz estimated that he could construct the big power stations for £8.8 per KW. This was an extremely low figure and was attacked as impossible by the opposition. In the following year the L.C.C. brought out a scheme for an 80,000 KW power station using 10,000 KW turbo-alternators at an estimated cost of £15.8 per KW. This latter figure is about what good engineers thought might be obtained from big station incorporating the latest practice, and was considerably less than the £25 per KW and more which was what big power stations in the years 1900 - 05 had cost. The cost of Merz’s transmission and distribution system, although at the modest pressure of 12,000 v., was very low, and was similarly queried by opponents. Colonel Crompton told the Select Committee of the Commons on the Bill:

"When I studied the project, knowing Mr. Merz was a man who was an honest engineer, who thoroughly believed in what he was saying, and what he was doing I tried to find out for myself where he had deceived himself in putting down what appeared to be a ridiculously low figure as the cost of distribution in London .... and I confess the task of justifying Mr. Merz’s figure is beyond me. I think it is beyond any engineer who has had experience of laying mains anywhere in the world.... I think it ought to be doubled and very probably trebled. I should say treble was nearer the correct mark".

Merz was trying to do what Ferranti had attempted, and his opponents predicted the same failure. But although there are similarities there are considerable differences. Ferranti tried something quite revolutionary; Merz was going well beyond what had been done, but nothing


2. Except of course Carville.

3. House of Lords Select Committee on the Administrative County of London and District Electric Power Bill. Qs 6353 and 6854. Merz’s estimates were based on a tender from British Insulated and Helsby Cable Co.
like as far as Ferranti. The London stations were to be based on the very successful layout at Carville, but were to be about three times the size. Ferranti was a visionary and a genius, and allowed his imagination to influence his calculations. Herz was equally a brilliant engineer and a man of vision, but his calculations were very precise and his predictions usually accurate, certainly as close to the mark as those of his conservative opponents. His scheme seemed more radical than it was because of the backwardness of British electrical engineering; in the United States and in Germany it would have been more easily accepted. Capital cost estimates of these schemes are nearly always on the low side, but even if the actual costs had been as much as 25% more than estimated it would have been a very cheap scheme. Not that there is any reason to suppose underestimation. Running costs also were to be very considerably less than those of existing stations. Running costs vary usually with the load factor and Herz hoped for one more than double that of the average London undertaking. After making a rough correction for this Herz's estimated running costs seem to have been between a fifth and a

1. It is worth quoting Professor A.B.W. Kennedy, under examination: "The Promoters say that we are old and antiquated - the last word has not been spoken in electrical advance yet; will Mr. Herz be antiquated even in ten years after he has been established?" - "I feel quite certain that in 15 years from now we shall not be having a three phase transmission plant - we shall be having a single phase". This prediction, like Wordingham's on the same occasion, that the steam turbine was a "passing fashion", has not only turned out to be quite incorrect, but was clearly unjustifiable at the time.

2. ibid. Q 4573.
a quarter of the average and about a third of the lowest station. By using 10,000 kW turbo-alternators Merz hoped to reduce the amount of coal used per unit by 18% compared with the Carville turbines, which were roughly the size currently being installed at the best London Stations. Parsons and Brown were prepared to guarantee this. Building the power station on the river bank with good wharf facilities, would have reduced fuel costs compared with the inland stations. Cartage to the big power stations at Bow, Willesden and Bankside could cost between 1/11d. and 3/2d. a ton, a large proportion of the delivered cost of 11/- = 14/- a ton. Merz wanted to use Northumberland coal at a delivered cost of 7/4 at the power station. It had a thermal value of only about 75% of that of the Welsh coal then generally used but the thermal efficiency of the proposed stations would have been about double that of most recently installed plant. These factors would reduce coal costs per KWh generated by about 60%. Labour and repair costs would also have been very much lower per unit generated with larger plant.

The Administrative County Company thus proposed to supply at roughly one third of the costs of the best existing London stations. But

1. Average works costs were 1.46d. per unit generated for 39 undertakings. The best was 0.93d. Increasing the load factor to that forecast by Merz would have reduced them by about half. Merz estimated 0.15d. per unit generated for his station. The Central London Railway had a 55% load factor against Merz's of 35 - 40% and had a works cost of 0.544d. per unit generated (Q.2619) and West Ham hoped to get down to 0.416d. when a good power load had developed.

2. Carville's works costs, with cheaper coal, were 0.12d. per unit generated.

3. There is very little information on thermal efficiencies and comparisons are complicated by the load factor.
despite this it could still have foundered on overestimation of the rate of growth of demand. Merz had tried to calculate the demand for electricity. That for power was based on estimates of the total steam power in existence, that for traction on the existing suburban train service and that for lighting on an extrapolation of present trends. By 1910 when one of his proposed power stations would be in full operation he predicted sales of 64 million KWh for power, 50 million for lighting and 23 for traction. His power estimate was certainly not excessive; in 1910 the existing undertakings sold about 56 million KWh for power in the relevant area. As the Administrative County Company’s prices would have been lower and demand was probably elastic 64 million units would probably have been easily reached. For his traction sales Merz reckoned on suburban electrification. In fact there was scarcely any, although there might have been had there been a cheap enough supply. Traction sales by existing undertakers grew by less than one million units by 1910. For the lighting load Merz estimated his possible 50 million KWh on the basis of getting half the increase in output. By 1910 the actual increase in output in this class was only 39 million units. Demand was not elastic and so a reduction of prices would not have helped much. But what had completely upset his estimates here was the invention of the metal filament lamp, which cut by one half to two thirds the amount of current used for lights.


2. The company sought to sell power direct in the "industrial area" - the Eastern area - as well as through authorised distributors, and through authorised distributors only in the remainder of the area.

The Bill failed because the 1905 session of the House of Commons came to an end before it could be given a third reading. There was great opposition to it from the beginning from the existing suppliers and the L.C.C. It was first dealt with by a Select Committee of the Lords; there were 77 separate petitions against the Bill from over 1/20 authorities represented by some 35 counsel. After 5 weeks' proceedings the Committee decided to recommend the Bill, although not for the whole area asked for. But the L.C.C. continued as determined opponents and forced a debate on the second reading in the Commons, which was an unusual practice for Private Bills. The Bill's opponents dragged out the hearing before the Commons' Committee as long as possible, until there was very little time left for the third reading. It just got through the Committee in time, but although the Board of Trade favoured the Bill, John Burns on behalf of the L.C.C. combined with the Irish members and they were able to stop a collapsing government from putting the Bill through.

The Liberal government which followed was no friend to private schemes of this sort and in the following session, when the Administrative County Council Bill was again introduced, it was decided that the L.C.C. ought to be the bulk supplier, although their inadequate scheme was turned down. Finance had become difficult to get and expensive and it would have involved more borrowing than the Finance Committee liked and yet the Select Committee wanted the L.C.C. to spend twice as much on a really big

1. G.N. Marx, Private Notes.

2. Marx later wrote "one naturally asks whether anything could have been done to have saved the Bill. Short of an agreement with the County Council I do not think anything could have been." Private Notes.
scheme. Then came the L.C.C. election of March 1907. Expenditure on public works in general and electricity supply in particular was a major issue. The Conservatives gained a sweeping victory, and determined not to proceed with a bulk supply scheme. The Chairman of the L.C.C. Parliamentary Committee said that the promotion of another L.C.C. Bill would be a waste of the ratepayers' money. By then the L.C.C. would have preferred a big private scheme, but the Liberal Government was opposed to this and wanted an L.C.C. scheme. Thus the prospects for any private Act of Parliament were slim. The cost of a private promotion was very high, the Administrative County Company had spent £50,000 in vain, and the two things in combination were enough to deter any private promoters.

There the matter rested. Acts of 1908 and 1910 allowed existing suppliers to associate, subject to the approval of the Board of Trade, to supply power to each other and to work common generating stations. Not much was done; in 1909 a joint committee of municipal and company engineers did not recommend a general linking up, being satisfied that existing stations were capable of meeting all requirements for the next ten years. From one point of view there was much to be said for their recommendation. Only Kersh's plan was a sufficiently radical innovation to reduce costs very greatly by an overall scheme. Between 1905 and 1913 the London suppliers added 131,753 KW of capacity to their generating stations, spending £4.2 million. Power stations would account for no more than half of this - i.e. about £16 per KW added. It was a

1. E.R. Vol. 61, PP 1 - 2. 5 July 1907.
a lower figure than the national average, because it merely involved extensions to existing power stations. It was something like the best estimates of the L.C.C. and the bigger existing suppliers in 1905 and 1906. But it was about twice what it could have been.
Chapter 5.

Electric Traction.

The story of electric traction falls into three parts: the electric tram, electric urban railways, principally London underground, and the electrification of suburban railway lines. A fourth section on the extent to which lighting and traction were complementary follows.

Electric trams started late in this country, being first almost entirely an American import.

Table 34

<table>
<thead>
<tr>
<th>Year</th>
<th>Great Britain</th>
<th>Germany</th>
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<th>Other European Countries</th>
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</table>

* Includes elevated railways. Figures are for route mileage except for the United States where they are for miles of single track.

They had been pioneered in the United States, and electric traction had soon become more important than the old horse trams. As early as 1892 51% of the tramway mileage was worked electrically, and by 1897 88%. In Great Britain only 9% of the mileage was run electrically in 1897 and only by 1905 had it risen to 89%. The Continent of Europe had also adopted trams after the Americans and there the early electric tramways were constructed on American lines. In Germany in 1895, 98 miles of electric tramway were under construction, and of this 81% was on the Thomson Houston and Sprague systems (both American). In other countries the same is true. But in these countries the American innovation was digested more rapidly than in Great Britain. By the middle nineties there was a boom in electric tramway construction and German manufacturers were quick to make tramway equipment. In England there was scarcely any activity until 1897.

One reason for the delay was the effect of the 1870 Tramways Act. This was passed to facilitate the construction of the then brand new horse trams, and to provide some public control of them by stipulating that the tramway should be able to be bought by the relevant local authority after 21 years operation, at the plant value. By 1878, 269 miles of horse tram had been built, and another 542 miles were added between 1878 and 1885. Thereafter mileage grew more slowly. By 1889 the horse trams reached their maximum mileage of 940; they remained at

1. See H.C. Passer, op.cit., Chapters 15 and 16.

<table>
<thead>
<tr>
<th>Year</th>
<th>£000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to &amp; including 1893</td>
<td>530</td>
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<tr>
<td>1894</td>
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<tr>
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<td>1,532</td>
</tr>
<tr>
<td>13</td>
<td>1,613</td>
</tr>
</tbody>
</table>

1. Before 1904, the figures are rough estimates, based on mileage open and the total capital spent by 1903. The first complete Board of Trade Returns are for the end of 1903. The 1898 - 03 estimates for

.. may easily contain an error up to 20\%.
that level until 1899 when they began to be replaced by the electric tramway. Thus a large mileage would have been purchaseable between 1899 and 1906, and some of course earlier. In general the tramway undertakings never felt that they would get more than the "scrap" value of their plant on compulsory purchase and that ten years was too short a time to get an adequate return on electrification.

This was strongly reinforced by the low profits of the horse trams. In the early nineties these were almost certainly operated at a loss. Depreciation allowances were inadequate, equipment was often in poor condition and dividends were often below the long term rate of interest. Receipts probably covered no more than 80 - 90% of real costs. Even in the 1870's there were few profits. Gross profits in 1878 were only 5.5% on historical cost. From 1878 to 1895 they seem to have built ahead of demand and the gross profit percentage had fallen to 4.9%. But it is difficult to believe that depreciation and interest amounted to less than 8% of the value of plant. In the late eighties 30% of the tramways paid no dividends. In this situation there was no enthusiasm to try and find the considerable capital required for electrification. The generally low demand for tramway transport would

1. This is argued by Vesey Knox, The Economic Effect of the Tramway Act 1870, Economic Journal, 1901, P. 507.
2. The capital expenditure figures given in the Tramway returns are unsatisfactory because depreciation was generally inadequate. This would give the profit percentage a tendency to fall over time.
3. E.R. Vol. 26, P. 717. June 1890. This is no doubt an approximate percentage.
not have encouraged the building of new electric tramways where there were no horse trams. For although there were only 131 tramway systems in this country in 1890, they were in general in the centres of large towns where demand was highest per route mile. But demand continued to grow after 1835 although capacity was added to more slowly. Table 36 attempts to give an index of capacity utilisation. As a consequence of this growth of demand relative to capacity gross profits as a percentage of historical cost rose to 5.3% in 1894, and 6.4% in 1898. This probably underestimates the real rise in profitability.

Table 36.

<table>
<thead>
<tr>
<th>Year</th>
<th>Passengers p.a. per route mile</th>
<th>Passengers p.a. per car</th>
<th>Index of passengers p.a. per car &amp; per route mile</th>
</tr>
</thead>
<tbody>
<tr>
<td>1878</td>
<td>543</td>
<td>131</td>
<td>100</td>
</tr>
<tr>
<td>1886</td>
<td>444</td>
<td>115</td>
<td>84.8</td>
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<tr>
<td>1890</td>
<td>555</td>
<td>133</td>
<td>103.9</td>
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<tr>
<td>1894</td>
<td>633</td>
<td>147</td>
<td>114.4</td>
</tr>
<tr>
<td>1898</td>
<td>807</td>
<td>161</td>
<td>135.7</td>
</tr>
</tbody>
</table>

* Obtained by combining columns 1 and 2 with equal weighting.

Source: Board of Trade Returns.

Some municipalities had been interested in tramways from 1870. But these were only a few, and by 1890, 26 local authorities had spent only £2.9 million on capital account against £10.8 million by 165 companies. Moreover only Huddersfield was actually working its lines, the others being leased to a company. But in the early 1890's the municipalities sought to become operators as well as owners of the tramways and from 1892 many important municipalities obtained operating powers. Having leased the tramways would have made it more difficult to change the form of motive power, but the corporations showed little desire to do this in any case. As in the case of electric supply in the early nineties they were not anxious to innovate; they still saw this as the function of private enterprise.

This was not universally true: Bradford, which had built the first municipal power station started experimenting with electric traction in 1892. Against this however one can quote the example of Glasgow, whose tramways were leased to a company. When the lease expired in 1894, the Corporation started to work its trams. Its first act was to buy 3000 new horses. In 1895 - 6 they started to consider electric traction, but it was as late as 1898 before they had equipped as little as 2½ miles of electric tramway.

In the event private innovations largely failed to materialise. The very early experiments with electric trams had not been encouraging.


One of the crucial technical problems at first was getting the electricity to the tramcar, eventually solved by the use of the overhead trolley. A conduit line 2 miles long was built on Blackpool Promenade in 1885 but it did not work well. Insulation was poor in the conduit and the plough was regularly fouled by dirt. Also the tramway motors gave trouble.

Another early system was with accumulators on the trams. The idea of accumulator trams was attractive as few modifications needed to be made to the horse tram systems. But despite constant experimentation from 1882 onwards, they were never satisfactory. At first they continually broke down but eventually by the late eighties some battery cars had been made to operate adequately but they were excessively costly. One experiment with accumulator cars was at Barking. The North Metropolitan Tramway Co. was approached by the Eleison Electric Traction Co. in 1889. The latter wanted to work a small part of the former's lines with accumulator cars. They were to be paid 4d. per car mile, the cost of horse traction. But the Electric Traction Co. suffered from so many breakdowns that they were unable to run to the full scheduled service. After 2 years they asked to be paid 5½d. per car mile. The Tramway Company agreed to do this for 12 months, although it made the system

1. H.C. Passer, op.cit., Chapters 15 and 16.
2. The electric cables were laid in a slotted conduit in the ground between the rails and contact made by a plough.
3. Elec. 31 Octo-er 1885, 7 May, 24 September 1886.
more costly than when run with horses, but before that period was up
the traction company asked for 7½d. They were offered and took 6½d.
The number of breakdowns began to increase and on July 12th, 1892,
the North Metropolitan Co. decided to return to horses. The real costs
of accumulator traction in this case are unknown, as despite many attempts
by the Tramway Co. to be given full running costs, these were never forthcoming. The Tramway Company thought that costs wore about 9d. per car
mile. Accumulator cars also were tried in Birmingham. In 1891, the
first year of operation, the cost of power and repairs to machinery was
5½d. per car mile, which was somewhat above the usual cost of horse
traction, but the speed of operation was a little higher as other costs
fell to compensate. But power and repairs rose to 9½d., 10.6d., 9.7½d.,
13.2d. in the following four years. It was an accumulator locomotive
system and by 1894-5 track repairs were costing over 2d. a car mile, a
figure much the usual horse cost. Receipts per car mile were unusually
high, averaging 15.5d. over the five years, but scarcely high enough.
Accumulators continually broke down at considerable expense; in 1892 the
Electrical Review quotes someone responsible for working them "We patch
them up by night, and the following day the patches come off".

In the early 1890's the American system of the overhead trolley
did begin to appear. In 1891 the South Staffordshire Tramway decided

   and 364 - 5. Taken from the Railway World.
to adopt electric traction on the overhead system. This was a steam
line 23 miles long in the Walsall, Wednesbury and West Bromwich area, and
after many complaints the local authorities withdrew their permission to
use steam engines. A. Dickinson, the general manager, and F. Brown,
the electrician to Walsall Corporation, made a tour through the U.S. to
report on the electric tramways. They came back impressed and in 1892
the Electric Construction Corporation was commissioned to equip 9 miles
on the overhead system. Meanwhile, Craft Baker, an American engineer,
constructed a tramway on the Texas-Houston system at Leeds. This
operated successfully at Roundhay, some distance from the centre of the
city.

But despite this there was no general enthusiasm for electric
trams by the middle nineties. The trade cycle worked against possible
promoters of new schemes. Money was difficult to raise for new electrical
ventures after 1890. There was also the general indifference of English
electrical manufacturers. They had experience of electric traction
admittedly only on the 3rd rail system, which was unsuitable for trams,
but they played no part in the important innovations, and seemed to show
little interest in them. This was partly because of financial difficulties.
To create a demand they would have had to finance electric traction
experiments themselves and after 1891 - 2 they were illiquid. Further
borrowing would have been difficult and expensive, yet in 1894 Ferranti

1. B.R. Vol. 29, PP 350 - 1. 25 September 1891
2. One of the main U.S. systems. C. Klaasen op.cit., P 25.
commented ... "everything of a new nature required an immense amount of personal effort and continual work to bring it forward. Electric traction required all the energy of the whole electrical industry ..."

With no-one able to demonstrate in practice the advantages and costs of electric trams there was little knowledge of either by 1895. It is in this situation that one can appreciate the great contemporary argument against electric overhead trams - that the wires were so hideous as to be intolerable. This was used to a surprising extent in the first half of the nineties, although as one might expect, when the utility of electric trams had finally become obvious to all, it was discovered that overhead wires could be made quite unobtrusive. The aesthetic argument was an excuse for delay rather than a good reason.

In 1897 Manchester Corporation decided to change over to electric trams on the overhead system. It was on all grounds except one the best, and the only objection, the aesthetic one, was disposed of as follows - ...

"The overhead construction has been brought to such a state of perfection that the objection on aesthetic grounds is extremely small; indeed there are probably not half a dozen streets in the finest cities, architecturally speaking, in the world in which it would be held to be a disfigurement. Certainly in our opinion, it would be none in the busy commercial streets of Manchester in which the trams at present run".

The middle nineties saw the formation of British Thomson-Houston. It was largely financed from Germany but was staffed by American engineers.

2. Report of Lloyd Higginbottom, Chairman of Electricity Committee, John Phythian, Deputy Chairman, and C.H. Wordingham, City Electrical Engineer, 11 October 1897.
This gave a great impetus to tramway electrification. Its first customers were the Bristol and Dublin Tramway Companies. Both were connected with the Imperial Tramway Company which in 1891 appointed J. Clifton Robinson to its staff. Robinson, born in Birkenhead in 1848, had worked in trams ever since he had been employed by G.P. Train, the horse tram pioneer. He had from the early days been an advocate of mechanical traction, first the cable, then electricity. He had spent the late 1880's in California, where he had seen the American innovations in electric traction. After his return to this country he had begun a series of conversions of trams to electricity, starting at Bristol and Dublin. He worked closely with B.T.K., who completely equipped the Bristol-Kingswood line, opened in October 1895, and the Dublin line, where in 1896 B.T.K. were equipping 6½ miles of overhead system. The initiative was partly B.T.K.'s and they followed these pioneer lines with a number of proposals to existing undertakers. In January 1896 they wrote to the Town Clerk of Newcastle upon Tyne where the Council had been debating tramway improvements, principally hinging on building a cable tramway. They offered to equip the line owned by the Corporation and lease it for 7, 10, or 21 years, supplying their own trams. They would charge the fares suggested by the Town Improvement Committee. They also proposed to pay a 7½ rent on the cost of the reconstruction of the lines, 3½ on the value of the land, and 15½ of the net profits. In December 1896 they wrote in similar terms

The success of the Dublin and Bristol schemes, the very successful tramways of the U.S., and the beginning of substantial electric tramway construction in Germany all combined with the rising demand for tramway transport to start off substantial electric tramway construction in this country. The Imperial Tramways expanded their schemes. In 1896 the Bristol Tramway Company promoted a Parliamentary Bill for wide extension of their electric trolley track into Bristol. By 1898 the Middlesbrough, Stockton and Thornaby tram had been electrified under J. Clifton Robinson. B.T.H. supplied all the equipment and H.F. Parshall, B.T.H.'s American chief engineer, had supervised all the work. In that year they proposed a big scheme for the London United Tramways. 9 miles of existing track were to be electrified and another 34 miles added.

The other tramway companies still showed little interest, but a large scheme for electrifying tram was put forward by the British Electric Traction Co. This company was formed in October 1896 with the object of gaining control of existing undertakings and electrifying them. By the end of 1897 arrangements had been made in 19 places for adopting electric traction. By March 1899 B.E.T. had financial interests in 40 companies. Also it wanted to build new tramways where none existed. B.E.T. soon came to dominate company tramways. 37 of them were electrified and

2. 6½ miles, mostly of double track were involved.
extended by B.S.T. As Table 37 shows B.S.T. affiliated tramways carried
the majority of the passengers who travelled on company tramways. The
B.S.T. scheme were on the overhead trolley systems; they were simply
applying the American innovation. The private promotion of new tramways
was helped by the Light Railways Act of 1896. It was originally intended
for light railways in rural areas, but the clause giving the local
authority powers to purchase was much more liberal than the 1870 Tramways
Act. The period before purchase was to be agreed with the local
authority. 30 years became the usual period.

The municipalities were also involved on a large scale in the
tramway investment of the late nineteenth. In May 1895 Leeds Corporation,
pressed by the Thomson-Houston system at Rawmarsh decided to electrify
on the overhead system. By 1897 19 miles were in operation. Bradford
also had 2 miles of permanent electric track by 1896. But the real
movement started in 1897 when Liverpool, Glasgow, Manchester, Sheffield,
Southampton, Halifax, Hull, Hastings, Sunderland, Wigan and Blackpool
decided to construct overhead trolleys. Lacking information, a deputation
of the Town Councillors would go to Company to look at the new electric
trams, or more economically, to Bristol. Sometimes deputations were sent
to the United States. Glasgow, perhaps the most thorough town of all,
sent deputations to 11 Continental towns and to the United States in 1896.
Such expeditions were thought necessary to ensure that they were not

1. Report of Tramway Committee of Leeds Corporation. S.R. Vol. 36,
PP 620 - 1. 17 May 1895.

2. S.R. Vol. 41, P 426. 29 October 1897.
<table>
<thead>
<tr>
<th>Year</th>
<th>Local Authorities</th>
<th>% of Total</th>
<th>Companies</th>
<th>British Electric Traction</th>
<th>% of Others</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>British</td>
<td>Electric</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>% of Total</td>
<td></td>
<td>Electric Traction</td>
<td>Company</td>
<td>Total</td>
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<td>1903-4</td>
<td>1426</td>
<td>79</td>
<td>220</td>
<td>59</td>
<td>153</td>
<td>1799</td>
</tr>
<tr>
<td>1908-9</td>
<td>2020</td>
<td>79</td>
<td>255</td>
<td>54</td>
<td>345</td>
<td>2660</td>
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<tr>
<td>1913-14</td>
<td>2699</td>
<td>79</td>
<td>730</td>
<td>2</td>
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<td>3429</td>
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</table>

1. Companies Year ending December, Local Authorities year ending March.
2. B.E.T. figures not available.

Source: Board of Trade Returns and Garko's Manual.
engaging on a speculative venture. They took a long time deciding what they ought to do but one they had made up their minds they were usually quick to act. The wave of tramway construction which followed was dominated by the municipalities.

The only large town where the electrification and extension of trams was seriously delayed was in London. Although the L.C.C. had obtained powers to run tramway in 1896, and London was badly served by trams, they did not consider major tramway extensions and the use of mechanical power until 1900. By 1905 when other big towns had eliminated them the L.C.C. carried 23% of its passengers south of the Thames by horse tram.

Alone of the local authorities they were still sure that the overhead trolley was too ugly to be adopted and resolved to build all their lines on the conduit principle. They were following the practice of many capital cities: Berlin, Brussels, Budapest, Washington D.C. and New York had conduit systems, but they were very much more expensive than the overhead trolley, both to build and to work. F.S. Pearson, the engineer to the New York conduit line estimated that the cost of cleaning and maintenance was £180 p.a. per mile against £60 with the overhead system while it cost £9,643 per mile of single track to build against £5,822 on the overhead system. The engineer of the Washington

1. The L.C.C. tried to force the L.U.T. to adopt a conduit for the 4 miles of its lines which were inside the Administrative County, but Parliament overruled it.

and Baltimore conduit line estimated its cost per mile of double track at £17,221 against £8,926 for the overhead. Thus an expensive system was adopted, and to make matters worse actual expenditure exceeded estimates by a wide margin. At first the cost of the first 200 miles of track was estimated at £3 million; by 1903 it had risen to £5 million. The adoption of this expensive system was to have unfortunate repercussions later.

The overhead trolley turned out to be an innovation which substantially reduced costs. When it was first considered it tended to be thought of as reducing costs by providing a cheaper form of motive power, but eventually this proved to be a minor point. Much of its economic value lay in its increased speed and carrying capacity. The electric tram travelled at a speed roughly half as fast again as that of horse cars in crowded street conditions, and relatively faster in the suburbs. The much more powerful electric motor meant also that the size of the tram could be increased so that instead of carrying about 25 people the double decker electric tram could carry 60. The electric tram improved the value of the transport offered, by raising speeds. But it also benefitted the community by providing transport which used less resources than the horse trams, and this also was partly because of higher speed.

It is difficult to conduct a precise analysis of costs, for there

1. Report to Manchester Corporation, ibid., These figures agree well with other contemporary ones.

is inadequate information about capital costs. But the general outline is clear.

The best unit of output to take is the car mile. The size of capital expenditure was primarily a function of the mileage of track. About 75% of the investment of a tramway was in its track, overhead equipment and power station, when it had one. Expenditure on trams and horses remained a fairly constant proportion of aggregate capital expenditure. This we should expect, as there is a fairly constant ratio of tramcars to the route mileage. Table 36 gives capital expenditure per mile of single track. Other figures are in route miles and as double track was usually used I have doubled these figures. It is difficult to know what charges to make for interest and depreciation. I have taken 3% interest charge throughout, 5.0% p.a. depreciation for electric trams and for horse trams 6.5% in 1878 and 7.2% in 1893. Except for horses these depreciation figures are considerably higher than the depreciation provision made by the tramways themselves yet I do not think they are too high. In Table 39 capital costs per car mile are calculated on this basis and working costs and receipts per car mile have been taken from the Board of Trade Returns to show total costs and profitability.

1. About half the electric tramway mileage in the country was supplied by tramway power stations.

2. Assumptions are based on years of life of equipment. They are:
   - Electric cars 12 yrs. (300,000 miles)
   - Other equipment 25 yrs.
   - Horses 3 yrs.
   - Horse cars 13 yrs. (300,000 miles)
   - Other equipment 30 yrs.
Table 38.

Tramways. Capital Utilisation and investment.

<table>
<thead>
<tr>
<th>Year</th>
<th>Cars per route mile of track</th>
<th>Car miles per car p.a.</th>
<th>Car miles per route mile p.a.</th>
<th>Capital expenditure per mile of single track £</th>
<th>% of Capital expenditure on track &amp; power station</th>
</tr>
</thead>
<tbody>
<tr>
<td>1873</td>
<td>4.2</td>
<td>16.7</td>
<td>70</td>
<td>9877</td>
<td>79.5</td>
</tr>
<tr>
<td>1886</td>
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<td>1894</td>
<td>4.3</td>
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<td>25.3</td>
<td>125</td>
<td>18332</td>
<td>75.1</td>
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</table>

* 1879.

Source: Calculations from the Board of Trade Returns.
Table 39.

Tramways. Costs and Revenue per car mile.

<table>
<thead>
<tr>
<th>Year</th>
<th>Working costs per car mile</th>
<th>Capital costs per car mile</th>
<th>Total costs per car mile</th>
<th>Receipts per car mile</th>
<th>Surplus (+) or Deficit (-) per car mile</th>
</tr>
</thead>
<tbody>
<tr>
<td>1878</td>
<td>-</td>
<td>6.4</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>1895</td>
<td>9.2</td>
<td>6.3</td>
<td>15.5</td>
<td>11.9</td>
<td>-3.6</td>
</tr>
<tr>
<td>1898</td>
<td>9.3</td>
<td>6.1</td>
<td>15.4</td>
<td>12.1</td>
<td>-3.3</td>
</tr>
<tr>
<td>1906</td>
<td>6.6</td>
<td>5.8</td>
<td>12.4</td>
<td>10.7</td>
<td>-1.7</td>
</tr>
<tr>
<td>1910</td>
<td>6.6</td>
<td>5.7</td>
<td>12.3</td>
<td>10.6</td>
<td>-1.7</td>
</tr>
<tr>
<td>1912</td>
<td>6.7</td>
<td>5.6</td>
<td>12.3</td>
<td>10.7</td>
<td>-1.6</td>
</tr>
</tbody>
</table>

1. Car miles per route mile p.a. estimated.

Source: Calculations from Board of Trade returns.

Despite the higher investment per mile of track, electric trams seem to have been capital saving per unit of output. This was achieved by using their higher speed for a relatively intensive rather than a relatively extensive service. For the trams were primarily for urban areas.

Operating costs also fell dramatically. The cost of horse traction per car mile was high, between 3.5d. and 4.5d. in the nineties. The amount of electricity used per car mile varied between one kWh for the small cars of around 1900 and two for the double deckers of 1913.
Table 4.0.

Electricity used per car mile kWh.

<table>
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<tr>
<th></th>
<th>Companies</th>
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<tr>
<td>1905</td>
<td>0.95</td>
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<td>1908</td>
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<tr>
<td>1913</td>
<td>1.42</td>
<td>1.90</td>
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</tbody>
</table>

Energy cost 2d. - 3d. per kWh in the nineties, but fell to 1d. - 2d. by 1906 when the conversion to electric traction was complete. Thus when electric trams were first introduced the cost of traction per car mile was about 2.5d., roughly 60% of the cost of horse traction. By 1913 the power cost per car mile of a large double decker tram must have been still only 2.5d.

Traffic expenses, mainly the wages of operating crews, fell with the increased speed of electric trams. They were half as fast again as horse buses and with this increase traffic expenses fell by about two thirds, from about 3.5d. to 2.5d. per car mile. Management costs were partly overheads and partly varied with the car mileage. In so far as they were overheads they would have fallen with increased speed.

The relatively low operating costs of electric traction are strikingly shown in Table 4.1.
Table 41.

Tramway operating expenses. 1900.
d. per car mile

<table>
<thead>
<tr>
<th>Maintenance of permanent way</th>
<th>5 horse lines</th>
<th>5 steam lines</th>
<th>8 electric lines</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power</td>
<td>0.44</td>
<td>1.30</td>
<td>0.77</td>
</tr>
<tr>
<td>Renewals &amp; Repairs to cars</td>
<td>3.72</td>
<td>3.51</td>
<td>1.38</td>
</tr>
<tr>
<td>Traffic expenses</td>
<td>1.10</td>
<td>2.24</td>
<td>0.83</td>
</tr>
<tr>
<td>Other expenses</td>
<td>3.05</td>
<td>2.32</td>
<td>2.67</td>
</tr>
<tr>
<td></td>
<td>1.15</td>
<td>1.31</td>
<td>1.15</td>
</tr>
<tr>
<td></td>
<td>9.46</td>
<td>10.63</td>
<td>6.85</td>
</tr>
</tbody>
</table>


The capacity of trams rose very considerably, and this would not have been possible without electrification. Thus costs per passenger seat mile fell at least twice as fast as costs per car mile. Loading did not however increase. The service improved, many more people travelled, but about the same number rode in each car. (Table 42)

By comparison the other possible forms of mechanical traction, steam and cable, were much inferior. Steam trams offered little if

1. It is impossible to be more accurate than this as the average capacity of trams is not known.

2. Worked by an endless cable working in a conduit between the tracks. The car has a gripper which is released for stops.
any cost advantage over horses. Power was expensive, partly as smoke-
less fuel was expensive, partly as the steam engine is very inefficient
when stopping and starting. Although the greater speed reduced traffic
expenses it made up for this by greater wear and tear on the lines. But
they were used. In the middle nineties there were rather over 500 steam
trams in Britain.

Table 42.

Utilisation of Tramways.

<table>
<thead>
<tr>
<th>Year</th>
<th>Passengers per car mile</th>
<th>Passengers per route mile p.a. 000</th>
</tr>
</thead>
<tbody>
<tr>
<td>1878</td>
<td>7.7</td>
<td>543</td>
</tr>
<tr>
<td>1893</td>
<td>9.5</td>
<td>807</td>
</tr>
<tr>
<td>1902</td>
<td>9.6</td>
<td>940</td>
</tr>
<tr>
<td>1906</td>
<td>9.1</td>
<td>1,025</td>
</tr>
<tr>
<td>1910</td>
<td>9.4</td>
<td>1,194</td>
</tr>
<tr>
<td>1912</td>
<td>9.6</td>
<td>1,204</td>
</tr>
</tbody>
</table>

* 1879.

Source: Board of Trade Returns.

1. C. Klapper, op.cit., p 47.
2. ibid.
Cable trams were seriously considered, and were actually installed in a few places. But the capital cost was high and in return the running costs seem to have shown no improvement on those of the electric overhead, except where the density of traffic was very high. Power costs were in general no lower than those of the electric tram and maintenance costs were higher. However the major economic disadvantage was inflexibility. Cars could run at one speed only and if the cable broke, which it often did, all cars were immobilised. This, awkward for small systems in the centre of town, would have been intolerable with extended lines of 1905 - 15 carrying large numbers of passengers.

Demand for tramway transport was rising continuously from 1886. But both the series for total passengers and that for passengers p.a. per route mile increase more rapidly after 1894. From 1886 to 1894 inclusive passengers were increasing at an absolute annual rate of 30 million p.a.; from 1895 - 1899 this rises to 70 million p.a.

Passengers per route mile from 1886 to 1894 rose at an absolute annual rate of just under 50 p.a. and from 1895 to 1899 at one of 85 p.a. This coincides remarkably closely with the increase in the rate of building from 1895 onwards shown in S. Weber's figures. The tramways of the nineties were short but at least took people part of the way out to the suburbs. And the nineties were a period of migration to the towns.

Figure 1. Tramways

(a) passengers p.a.
(b) passengers p.a. per mile
Table 43.

Migration to the Towns 1831 - 1911

Gain (+) or loss (-)

<table>
<thead>
<tr>
<th>Year</th>
<th>Change</th>
<th>Passengers</th>
</tr>
</thead>
<tbody>
<tr>
<td>1831 - 91</td>
<td>-</td>
<td>31,185</td>
</tr>
<tr>
<td>1891 - 1901</td>
<td>+</td>
<td>294,346</td>
</tr>
<tr>
<td>1901 - 1911</td>
<td>-</td>
<td>89,263</td>
</tr>
</tbody>
</table>

London has been omitted because of its peculiar transport situation which merits particular attention. The figures cover 126 towns.

Source: A. K. Cairncross, Home and Foreign Investment, 1870 - 1913, P. 70

It seems highly likely that building and migration increased the demand for tramways. Short of a completely disaggregated study of building and tramway experience in individual towns one's conclusions must be uncertain. But aggregates do cast a little light on the matter. The tramways were in the big towns. The boroughs with populations of more than 25,000 had 14.8 million inhabitants in 1891 and 18.4 million in 1901. Dividing the numbers of tramway passengers by these populations we get 33 and 71 respectively. If the number of tramway passengers had grown throughout the decade at roughly the same absolute rate as from 1891 to 1894, the index of journeys per head would have been 40 in 1901. Thus if population increase in the towns was steady throughout the decade the increase in passengers in 1891 - 4 could have been 1300 million as against the published 1153 million.

1. This is not a good figure for the number of journeys per head in the towns but will do well enough as a type of index number of average travel frequency. Undertakings established under the Light Railways Act are excluded from the published statistics before 1902. The 1901 figure of passengers is estimated, the estimate being 1300 million as against the published 1153 million.
simply have been because of population growth. If passengers had grown
at the same rate as in 1895 to 1893 (or 1899) the index of journeys
per head would have been 59. This may be said to be the rate of
increase due to building although of course such a conclusion can only
be very tentative. This assumes that the housing boom had the same
influence on the later stages as in the earlier. If it is correct
to assume this, the remaining increase must be due to the effect of the
electrification and extension of trams. They were much faster than
horse trams and fares were often a little lower, especially workers' fares. On these assumptions 28% of the increase in passengers up to
1901 was due to population growth, 50% to building and 22% to tramway
innovations. The building boom was not crucial to the decision to
electrify in a number of cases at least, but it probably affected the
length of line finally built and perhaps the timing of conversion.
Many local authorities had in the early and middle nineties been generally
investigating mechanical traction. Cable and steam traction, particularly
the former, were considered. But the Thomson-Houston lines and
developments abroad showed that the electric overhead system was much
cheaper and also faster and more flexible.

The electrification of the tramways, and the extension that
went with it brought an increase of demand of itself. This was helped
by a reduction of fares. Many municipalities reduced fares when they

1. The passengers figures for 1895, 97, 98 & 99 all lie on the line
of equal absolute growth assumed in the calculations.
took over the running of tramways. Liverpool Corporation reduced fares by 30% when they took over and electrified the tram. In Manchester the average fare per mile if the full stage was covered fell from 0.93d for the horse cars to 0.43d for the municipal electric cars after 1903. By 1914 it was down to 0.35d. They were especially anxious to have cheap workmen's fares. Often when a company was allowed to work the tram, low workmen's fares were insisted on. To construct an index of fares is virtually impossible and the following table of receipts per passenger suffers in that the length of journey is unknown. What is likely is that the average length of journey travelled rose at the time when the trams were being extended and speeded up.

Table 44.

<table>
<thead>
<tr>
<th>Year</th>
<th>Average receipts per passenger d.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1892</td>
<td>1.46</td>
</tr>
<tr>
<td>1894</td>
<td>1.41</td>
</tr>
<tr>
<td>1896</td>
<td>1.31</td>
</tr>
<tr>
<td>1898</td>
<td>1.27</td>
</tr>
<tr>
<td>1900</td>
<td>1.23</td>
</tr>
<tr>
<td>1902</td>
<td>1.15</td>
</tr>
<tr>
<td>1904</td>
<td>1.14</td>
</tr>
<tr>
<td>1912</td>
<td>1.12</td>
</tr>
</tbody>
</table>

Source: Board of Trade Returns.

1. C. Klapper, op.cit. PP 134 - 5.
The extent of the increase in demand was considerable. By 1905 there were 2,236 million passengers carried on the trams. If passengers had increased at the same absolute rate as in 1895-9 there would have been only 1,200 million. Individual towns tell the same story. In Dublin, Glasgow, Newcastle and Sheffield tramway passengers in the two years following electrification were 78%, 79%, 39%, and 53% greater than in the two years preceding electrification. Some traffic was gained from horse buses and cabs, but in the cases where figures are available it was less than 1% of the total increase.

By the end of 1903 the introduction of electricity had led to a doubling of the tramway mileage but thereafter the trams extended more slowly. In the four years 1899 to 1903 inclusive 776 miles of tramway were built; in 10 years from 1904 to 1913 another 834 miles were added. The tramway boom did not die away as quickly as the building boom but it declined at the same time.

In the United States tramway construction stimulated residential building, but in this country the effect was much less powerful. Before one can draw any very firm conclusions about the relationship between building and trams, a detailed study would have to be made of individual towns. In its absence one can only speculate on the likely strength of the influence of better transport on building. Better, i.e. faster and/or cheaper transport on building, reduces the cost (in money and/or time) of living in the suburbs. But the extent to which a given reduction in the cost of transport (money plus time) will stimulate the

Demand for suburban housing will vary. One would expect it to be considerable either if the income elasticity of demand for suburban housing, or the rate of growth of income was high. In the relevant period British incomes do not seem to have been high enough for one to expect a high income elasticity of demand for housing. Trams were always regarded as being rather proletarian, and thus it is the incomes of the artisan and lower middle classes that are relevant. Also at the time income per head was growing only very slowly.¹

In this situation one would expect better transport to stimulate suburban building only slowly. Contemporary evidence as to the matter appears at first to be rather conflicting. During the building boom 1895 - 1903 many people argued that better transport had led to considerable suburban building. Many of the witnesses before the Royal Commission on London Transport put forward this view. Yet after the end of the housing boom views begin to change. Writing in 1910 the Electrical Review commented "it was thought ... when electric trams were being introduced that they would help in the development of the suburbs, but while to some extent this has been realised it is generally admitted that it has proved somewhat of a failure. One could point to many miles of tramway built to open up a district but which on those sections are financially hopeless."²

However, these two views are not necessarily inconsistent. The low level of building in the 1880s and the considerable internal migration of the 1890s made a building boom in the late nineties inevitable. The situation of the new houses was no doubt considerably affected by transport facilities. But the influence of better transport on the amount of building may not have been large. The effect of current transport improvements perhaps prolonged the building boom, but their main influence on building may have been to determine the siting of suburban building in the next boom. In any case what is important here is that the effect was small in the short run. Investment in trams involved discontinuities. It was not likely to be undertaken unless the rate of growth of demand for tram journeys on a proposed line was high. Thus the fall off in tramway construction after 1903 is to be explained largely by the very slow rate of urban growth in Britain. It has been suggested that this is primarily due to migration, but the explanation of slow urban growth, if the argument of the last few paragraphs is correct, is not relevant here.

In Britain trams remained within the towns. By contrast much of the tramway building in the United States after 1900 was of inter-urban lines. By 1906 most British tramways had been electrified and extended to meet roughly all the urban demand at the time. Considerable extensions on the outskirts of the towns would not have been likely to be

profitable. Costs barely covered revenue as it was and costs per car mile were only kept low by frequent services. The only figures available which throw light on the frequency of service are those of car miles per route mile.s. If we assume a tramway day from 5.30 a.m. to 10.30 p.m., 365 days a year, on the average, there was a frequency of service of 6 - 7 minutes during 1905 to 1912. Fares were low, partly because working class incomes were low and it was feared demand was elastic, and partly because the municipalities wanted cheap travel for the working class. When passengers were paying a little over 1d. per fare about 10 passengers on the average throughout the day had to be on the tram to get a revenue of 11d. per car mile. J.R. Salter, general manager of the Lancashire United Trams in a paper in 1910 stated that he thought that 11d. per car mile was as much as could be hoped for with the existing fare structure. And a well populated area was necessary for that.

If extension of lines on the outskirts of the town were unprofitable, inter-urban lines would have been less profitable. The fact inter-urban traffic was already catered for by the dense network of steam railways, which did not exist in the United States. Lack of co-operation between adjacent municipalities and bad relations between tramway companies and local authorities also delayed inter-urban tramway

connection. However, consideration of the cost and revenue situation of the tramways does suggest that political difficulties reinforced the effect of the economic situation.

It is significant in this context that the companies did not expand after 1905. Their enthusiasm of 1900 soon turned to disappointment as the electric trams were found to be not as profitable as had been thought. The British Electric Traction Co. was soon shown to have over-reached itself and its profits dried up. It was not in a position to borrow further, but in any case there were no financial inducements to do so.

Tramways ran through the streets, but any urban railway which wanted to operate at higher speeds had to go underground. Except in special areas elevated street railways would have been prohibited on aesthetic grounds. Steam traction was not suitable for underground operation, even though it had been used on the Inner Circle, which was completed in 1864. Yet there was a demand in the largest towns, and especially in London, for more rapid transport than could be provided by horses. As early as 1867 P.W. Barlow, who was an expert on tunnel construction, wrote a pamphlet advocating " Omnibus subways". There were other proposals for short underground railways, and in the 1880s...

a crop of such schemes. Cable traction was an improvement on steam
and in 1834 Parliament was asked to grant powers for the construction
of an underground line from the City to the Elephant and Castle, on which
cable cars were to be used. But electricity was obviously a competitor,
even in the middle eighties.

Siemens Bros. were the most important pioneers of electric
railways in Britain. Werner Siemens built an exhibition electric railway
in 1879, and a street railway (on the third rail system) in 1882. The
first electric railway in Britain was built in 1832—3 by Magnus Volk on the
beach at Brighton. He used Siemens equipment. At the same time the
promoters of a railway being built along the Grant's Causeway in Northern
Ireland decided to try electric traction and called in Siemens. Siemens
built the electrical equipment for the railway. However, for many years
electricity was used for only a small part of the traffic. Electricity was
at a relative disadvantage in a rural area but the technical success of the
line showed that electricity could be used in this way. William Siemens
died in 1833, but his chief assistant, Dr. Edward Hopkinson was very
soon asked to design an electric railway to run from Bessbrook to Newry.
He soon moved to Messrs. Hather & Platt, who had recently opened an
electrical department to manufacture the Edison-Hopkinson dynamo. The

1. As well as the ones discussed below there were Bills: in 1832 for
   for the Central Metropolitan Railway (King's Cross to Parliament Square);
   in 1834 for the London Central Electric Railway (Northumberland Avenue
   & Piccadilly to the Old Bailey); in 1835 for the Charing Cross and
   Euston Railway & the King's Cross, Charing Cross and Waterloo Railway.
3. Born 1859, was 10th Wrangler at Cambridge in 1881. In 1995 he
   became a Fellow of Emmanuel College, Cambridge.
latter was an improvement on the Edison dynamo made by Dr. John Hopkinson, Edward's brother. Thus Mather & Platt built the electrical equipment for the Bessbrook-Kewry line, which opened successfully in 1835.

In 1833, Mather & Platt approached the Directors of the City & S. London Railway, whose tunnels were already under construction, to try and persuade them to adopt electric traction rather than the cable. They succeeded and were awarded the contract for the electrical equipment. Siemens were also interested in the scheme. Alexander Siemens later told the British Association that "a perfect agreement had been arrived at (between Siemens and the City & South London Railway) on the technical points of the question," but that the contract had not been given to them "for financial considerations." Presumably Mather & Platt's prices were lower. Electric locomotives were to be used and Mather & Platt built the first 14, although in 1891 2 were bought from Siemens. The railway was opened in 1890, 3½ miles in length and extending south to Stockwell.

Siemens Bros. had also helped to promote an underground railway from Trafalgar Square to Waterloo, to be worked electrically. Parliamentary powers were obtained in 1882 but work on the railway was then abandoned in 1885.

The initial impetus behind these schemes was improvements in tunnelling. They stemmed from the original idea of the elder Brunel

3. T.S. Lascelles, op.cit., Appendix, P 34.
for using a shield, which protected the roof and walls while they were being bricked in. This was developed by Barlow, who patented the idea in 1864 and then by his pupil J.H. Greathead who was one of the original promoters of the City & South London line. It was the Greathead shield which made the deep tube lines possible. The combination of easier tunnelling and electric traction made "tube" railways seem very attractive. They promised rapid transport; the City & South London railway was to take 15 minutes to Stockwell against 45 by horse bus. London was growing big enough for there to be a demand for speed. In 1891 Parliament gave permission for the construction of a tube railway from Shepherd's Bush to the Bank of England, the first railway to cut through the centre of the metropolis. In 1892 a joint select committee of both Houses was set up to consider four new schemes and extensions to the existing two. The new ones were the Great Northern and City, the Hampstead and Charing Cross, the Waterloo and City and the Baker Street and Waterloo. The Central London Railway was to be extended to Liverpool Street Station and the City & S. London to the Angel, Islington. The Waterloo & City scheme was sponsored by the London & South Western Railway, who had since the fifties been considering an underground connection between the City and their terminal station. Early estimates had put the cost at £3 - 5 millions, but they found that electric traction could reduce the cost to £500,000

1. T.S. Lascelles, op.cit., PP 2 - 4.
2. The Central London Railway, part of present Central Line.
3. Now part of the present Northern Line.
4. Part of the present Bakerloo Line.
and decided to carry out the scheme. The other schemes were new ones. The Committee reported that "the evidence submitted to them was conclusively in favour of the sufficiency and the special adaptability of electricity as a motive power for the purposed underground tubular railways ..." and recommended that the scheme should be passed. The narrow tunnels used by the City & S. London were to be used. The L.C.C. wanted ones big enough to take the rolling stock of existing main line railways but the Committee agreed with the promoters that this would increase the cost so much as to run the risk that the proposed railways might never be built. So there was no possibility of running main line coaches through the tubes although the gauge was the same. The lines were to run under the street as the promoters wanted to avoid paying property owners for wayleaves. This was very unfortunate and was opposed by the L.C.C., who argued for the more direct routes. It is a clear case where private cost to the promoters exceeded social cost. They were also built some 60 feet below the surface, to avoid all difficulties which would be caused by disturbing sewers, gas mains, water pipes, etc. The shallow tunnels of the Inner Circle had been made very expensive because of this.

But actual construction was slow to start. Work did not start on the Waterloo & City line until 1894, or on the Central London Railway until 1895. The delay with other electric schemes was even greater.


2. Report of Joint Select Committee to consider electric and cable railways in the Metropolis, B.R.P. 1892, Vol. 12 Pt. II.
This in itself was not unusual; none of the schemes of the 1880s, except the City & South London were ever finished, and some never started. Work only really started when all the various schemes, except the Waterloo & City and the City & S. London, were taken over by the Americans. The Central London Railway came to life when it entered into a contract with the Electric Traction Co. Ltd. to build and equip its line. They were to be paid £2.5 million in cash and £700,000 in debentures. This was closely connected with General Electric, for E.W. Rice, one of the Vice Presidents of the latter, was closely involved with the construction of the Central London Railway, its electric equipment was manufactured at Schenectady, and was installed by British Thomson-Houston's American engineers. When it opened in 1900 its general manager was a Canadian.

The other lines were even more completely taken over. The story begins with the electrification of the Metropolitan Railway and the Metropolitan District, both suburban railways with lines into West London, but also joint operators of the Inner Circle. The latter line had been built initially to link up most of the main line railway termini, but had been added to by the various suburban


1. In 1846 a Royal Commission reported against a project for a great central railway station in London, a line being drawn which the main line termini were not to pass. At the time railway traffic was primarily goods. In 1855 when passenger traffic appeared, a Select Committee of the Commons suggested linking the existing station by an inner circle. In 1856 a Joint Select Committee advised Parliament to sanction an inner circle. It was not finally completed until 1894 when it ran past Paddington (Great Western), King's Cross (Great Northern) and St. Pancras (Midland), Liverpool Street (Great Eastern), Cannon Street (South East and Chatham) and Victoria (South East and Chatham, and London, Brighton and the South Coast). It had stations very close to Charing Cross (South East and Chatham) and close to Euston (London & North Western) and Fenchurch Street (Great Eastern & London, Tilbury & Southend). Waterloo (London and South Western), Holborn Viaduct (South East & Chatham) and London Bridge (London, Brighton & South Coast) were not served.


2. ibid. 0 19602

3. The Metropolitan did show some interest, but not very much. The District showed none.
the Board of Trade appointed a committee "to enquire into the existing system of ventilation of tunnels on the Metropolitan Railway, and report whether any, and if so what, steps can be taken to add to its efficiency in the interest of the public." The Committee thought, however, that the only satisfactory answer was electrification. It thought new ventilation holes should be permitted only on condition that electric traction was adopted within 3 years of the permissive Act.

Table 45.
Metropolitan & District Railways - Passengers p.a. millions.

<table>
<thead>
<tr>
<th>Year</th>
<th>Metropolitan</th>
<th>District</th>
<th>Inner Circle</th>
<th>London Central Railway</th>
</tr>
</thead>
<tbody>
<tr>
<td>1925</td>
<td>93.8</td>
<td>56.0</td>
<td>1.4</td>
<td></td>
</tr>
<tr>
<td>1927</td>
<td>101.3</td>
<td>53.6</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>1929</td>
<td>101.9</td>
<td>57.4</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>1930</td>
<td>99.0</td>
<td>55.4</td>
<td>1.5</td>
<td>14.9</td>
</tr>
<tr>
<td>1931</td>
<td>92.8</td>
<td>54.1</td>
<td>1.5</td>
<td>41.2</td>
</tr>
<tr>
<td>1932</td>
<td>95.3</td>
<td>48.8</td>
<td>1.5</td>
<td>45.3</td>
</tr>
</tbody>
</table>

Source: Electrical Trades Directory.

Over a year later the Chairman of the District Railway was at pains to point out to the shareholders that although they were seeking powers for electric running they were not going to rush into electrification. In November 1893 the two companies carried out experiments, whose results they thought satisfactory, but nothing more was done until the opening of the Central London Railway began to cut into their traffic.

By 1901, however, they had both decided to electrify, but despite the fact that they had joint lines and operated over each other's track, they chose different methods of electric traction, the Metropolitan wanting to try the new 3 phase traction being developed by Ganz & Co. and the District the standard d.c. traction used on most other electric lines. Eventually the Board of Trade had to arbitrate and decided in favour of the latter method. The change-over took place, but not until 1905 was there a full electric service.

It was not only lack of enterprise which delayed electrification. The District was in very bad financial shape. Its last ordinary dividend was in 1882 when it paid 3/6½d, and it was much in arrears on preference and guaranteed stock dividends. But in 1901, it came to an arrangement with Charles T. Yerkes, a Chicago financier, who together with a group of New York and Boston financiers and banks formed the Metropolitan District Electric Traction Company which was to supply most of the money for electrification. The Electric Traction Co. was to build a generating


2. The two lines had a long history of mutual antagonism, going back to the 1870s.
station which would sell electricity to the District and would re-equip its lines taking payment in shares. By 1903 £1,119,750 had been spent on the electrification of the District, 43% being paid for in 4% debentures and the rest in ordinary and preference stock. But in 1907 the Economist estimated the final cost of the electrification at £2.5 m. The District's Chairman, R.W. Perks, told the Royal Commission on London Traffic that if the Company had tried to sell £100,000 of stock in the market the price would have fallen below £20 (nominal value £100),

and even then they could not have sold it all.

The Metropolitan was in a better position, for it paid for the electrification of its line and also built a generating station of its own as it estimated it would supply current at 50% of the price offered by the Electric Traction Co. It seems that the Metropolitan was taking the initiative to some extent in electrification before the Yorks syndicate came on to the scene for it was stated at the half yearly meeting in August 1901 that the District had agreed to electrify on the Gems system, but that Yorks had persuaded it otherwise.

By 1902 Yorks also had control of the half started Baker Street and Waterloo Railway, the Hampstead and Charing Cross railway, the Brompton and Piccadilly, and the Great Northern and Strand. The last two had Parliamentary powers dating from 1897 and 1899; Yorks

2. Economist. Vol. 69, FP 2027 – 6, 23 November 1907.
got powers to merge them into the Great Northern, Piccadilly and 1 Brompton Railway. Then in April 1902 he, together with Speyer & Co. of New York and the old Colony Trust Company of Boston, formed the Underground Electric Railways of London Ltd. £16 million was to be spent in constructing (or completing) the lines which were to form one unified system.

The Baker Street and Waterloo and Piccadilly lines opened in 1906 and the Charing Cross and Hampstead in 1907. There were 2 interchange stations where they crossed with each other and where they linked with the District. The Yerkes tubes were equipped and run on standard American lines. Westinghouse built the generating sets for the Road power station, General Electric supplied the train equipments. 3 The fare system was American, the Central London started with a standard 2d. fare and Yerkes planned to introduce a uniform fare on each of the lines controlled by him. When in 1907 the Underground Company wanted a general manager for the tubes it controlled it chose A.H. Stanley, 4 the manager of the Public Service Corporation of the State of New Jersey.

By 1910 the Underground Railways Company accounted for 53% of

1. The present Piccadilly line.
3. Westinghouse and General Electric set up factories in England in 1900 and 1901 to exploit the traction boom. So much of the equipment was manufactured in England, but of course to American designs.
4. Later Lord Ashfield, first Chairman of the London Passenger Transport Board.
<table>
<thead>
<tr>
<th>Year to June</th>
<th>£000</th>
</tr>
</thead>
<tbody>
<tr>
<td>1897</td>
<td>847.9</td>
</tr>
<tr>
<td>93</td>
<td>769.5</td>
</tr>
<tr>
<td>99</td>
<td>1091.9</td>
</tr>
<tr>
<td>1900</td>
<td>2193.5</td>
</tr>
<tr>
<td>01</td>
<td>1128.0</td>
</tr>
<tr>
<td>02</td>
<td>2253.1</td>
</tr>
<tr>
<td>03</td>
<td>3872.5</td>
</tr>
<tr>
<td>04</td>
<td>7216.8</td>
</tr>
<tr>
<td>05</td>
<td>6075.1</td>
</tr>
<tr>
<td>06</td>
<td>4719.9</td>
</tr>
<tr>
<td>07</td>
<td>2925.6</td>
</tr>
<tr>
<td>08</td>
<td>468.3</td>
</tr>
<tr>
<td>09</td>
<td>461.0</td>
</tr>
<tr>
<td>1910</td>
<td>229.1</td>
</tr>
<tr>
<td>11</td>
<td>1158.2</td>
</tr>
<tr>
<td>12</td>
<td>305.0</td>
</tr>
<tr>
<td>13</td>
<td>3486.6</td>
</tr>
<tr>
<td>14</td>
<td>2072.8</td>
</tr>
</tbody>
</table>

Source: Garke's Manual,
Returns of the Railway Companies (B.P.P. various years)
<table>
<thead>
<tr>
<th>Year of opening</th>
<th>1884</th>
<th>1891</th>
<th>1893</th>
<th>1899</th>
<th>1904</th>
<th>1906 &amp; 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1892</td>
<td>1.5</td>
<td>6.2</td>
<td></td>
<td></td>
<td></td>
<td>7.7</td>
</tr>
<tr>
<td>1894</td>
<td>1.5</td>
<td>7.0</td>
<td></td>
<td></td>
<td></td>
<td>8.4</td>
</tr>
<tr>
<td>1896</td>
<td>1.4</td>
<td>6.9</td>
<td></td>
<td></td>
<td></td>
<td>8.3</td>
</tr>
<tr>
<td>1898</td>
<td>1.4</td>
<td>7.3</td>
<td>1.4</td>
<td></td>
<td></td>
<td>10.2</td>
</tr>
<tr>
<td>1900</td>
<td>1.5</td>
<td>9.7</td>
<td>4.1</td>
<td>14.9</td>
<td></td>
<td>30.1</td>
</tr>
<tr>
<td>1902</td>
<td>1.5</td>
<td>19.8</td>
<td>5.1</td>
<td>45.3</td>
<td></td>
<td>71.6</td>
</tr>
<tr>
<td>1904</td>
<td>1.3</td>
<td>19.1</td>
<td>5.4</td>
<td>44.9</td>
<td>8.3</td>
<td>79.0</td>
</tr>
<tr>
<td>1906</td>
<td>0.9</td>
<td>19.4</td>
<td>5.3</td>
<td>43.1</td>
<td>15.9</td>
<td>95.2</td>
</tr>
<tr>
<td>1908</td>
<td>0.6</td>
<td>22.7</td>
<td>4.9</td>
<td>41.9</td>
<td>12.3</td>
<td>85.8</td>
</tr>
<tr>
<td>1910</td>
<td>0.6</td>
<td>25.1</td>
<td>4.9</td>
<td>40.7</td>
<td>11.7</td>
<td>96.7</td>
</tr>
<tr>
<td>1912</td>
<td>0.5</td>
<td>28.5</td>
<td>4.9</td>
<td>36.1</td>
<td>12.8</td>
<td>100.9</td>
</tr>
</tbody>
</table>

* The District and Metropolitan lines, except for the Inner Circle, are not regarded as underground railways.

Source: Electrical Trades Directory.
underground passengers and 47% of the passengers on the tubes plus the Metropolitan and District, which were strictly not underground railways except for the inner circle, but which directly fed the underground network. In 1912 the Underground Railway Company acquired the Central London and the City and South London Railways. There were already interchange stations with the former at Oxford Circus and Tottenham Court Road. The latter had extended as far as Euston by 1907 where it met the Charing Cross and Hampstead line. It shared the Old Street station connecting with the Great Northern and City and at the Elephant and Castle it was connected by subway with the Baker Street and Waterloo line. The Underground Company intended to widen the tunnels and change the rolling stock, so that the line could be integrated into the rest of the system, but the war intervened and the line was not reconstructed until the twenties.

The short Great Northern & City was designed to link the Great Northern Railway to the City. It was perhaps the least successful of the tubes, partly because it went no further than Broad Street. In 1912 it was acquired by the Metropolitan who had the backing of the Great Western and the Great Central and plans laid to extend it to the Bank, where it would join the Central London, the Waterloo & City.

Thus except for the City & S. London, the Waterloo & City and the Great Northern & City, all the tubes were an extension into London of American electric railway innovations, much more completely

so than in the case of the trams. In view of the great criticism at the time of English backwardness in electric railways it is interesting to note that they did not cover their costs. The cost of construction seems to have been rather high.

Table 48.

<table>
<thead>
<tr>
<th>Route</th>
<th>Capital Expenditure per mile open</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1903 £</td>
</tr>
<tr>
<td>City &amp; S. London</td>
<td>377,200</td>
</tr>
<tr>
<td>Central London</td>
<td>631,600</td>
</tr>
<tr>
<td>Baker Street &amp; Waterloo</td>
<td>665,000</td>
</tr>
<tr>
<td>Charing Cross &amp; Hampstead</td>
<td>703,000</td>
</tr>
<tr>
<td>Great Northern &amp; Piccadilly</td>
<td>720,000</td>
</tr>
</tbody>
</table>

1. Not open in 1903.

The cost of the Yerke's lines may have been slightly inflated to yield a good return to the promoters.

Sources: 1903 - Evidence to Royal Commission on London Transport
1908 - Electrical Trades Directory.

Table 48 shows that the American equipped lines cost considerably more than the City & S. London. They were much better equipped in their capacity per mile was much higher, but it was many years before the traffic was large enough to justify this. The initial cost of the power stations was on the high side. The Central London one cost
### Table 49.

**London Electric Railways. Density of Traffic.**

<table>
<thead>
<tr>
<th>City &amp; S. London</th>
<th>1906</th>
<th>1910</th>
<th>1912</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>427</td>
<td>444</td>
<td>415</td>
</tr>
<tr>
<td>Waterloo &amp; City</td>
<td>161</td>
<td>166</td>
<td>133</td>
</tr>
<tr>
<td>Central London</td>
<td>710</td>
<td>596</td>
<td>498</td>
</tr>
<tr>
<td>District</td>
<td>226</td>
<td>280</td>
<td>324</td>
</tr>
<tr>
<td>Gt. Northern &amp; City</td>
<td>306</td>
<td>262</td>
<td>252</td>
</tr>
<tr>
<td>Baker St. &amp; Waterloo</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Charing Cross &amp; Hampstead</td>
<td>399</td>
<td>426</td>
<td></td>
</tr>
<tr>
<td>Piccadilly</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* The Metropolitan is omitted as it was worked by steam on its outer lines.

Source: Board of Trade Returns relating to Electric Railways in the U.K.

1. £34 per KW which was good for the late nineties but the Lots road station cost not much under £23 per KW although it was not completed until 1903. It was the largest power station in England at the time, with 5500 KW turbo generators but its cost compares very unfavourably with Carvillo which opened the following year. The electrification

2. Accounts of Underground Electric Railways of London Ltd.
of the District seems to have been expensive, without leading to low working costs. On the contrary the District’s working costs in 1906 were very high, being 53% higher per train mile in 1906 than under the old steam regime. The coaches were heavier and more comfortable but revenue had shown no signs of expanding enough to compensate for higher costs.

Traffic did not grow as Yorkes had expected, and the fares were too low for the degree of capital intensity chosen. In the United States the rate of growth of demand for transport was much higher, and by 1903 the New York subway, opened at the beginning of the century, reached the limit of its carrying capacity while in London travelling facilities seemed to have outgrown travelling habits. By 1907 the Economist noted that there was “an accumulation of evidence that the “tubes” are not financially successful.” They were highly efficient at moving people but as Table 50 shows never earned anything like an adequate return. This was only partly because of over expansion. The original prediction of the Central London Railway, given in its prospectus of 1895, was for 45 - 52 million passengers per year. They soon got all but 6% of this. The return on this traffic was no more than enough to pay a 4% dividend, and peak hour capacity had been

2. Economist. Vol. 64, P 1907. 9 November 1907
Table 50

Profitability of the Underground.

Gross profits as a percentage of capital expenditure.

<table>
<thead>
<tr>
<th>Year</th>
<th>City and S. London</th>
<th>Central London</th>
<th>Great Northern and City</th>
<th>Baker St.</th>
<th>Charing Cross and Waterloo</th>
<th>Piccadilly</th>
</tr>
</thead>
<tbody>
<tr>
<td>1895-6</td>
<td>2.2</td>
<td>2.2</td>
<td>2.2</td>
<td>2.2</td>
<td>2.2</td>
<td>2.2</td>
</tr>
<tr>
<td>96-7</td>
<td>2.5</td>
<td>2.5</td>
<td>2.5</td>
<td>2.5</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td>97-8</td>
<td>2.1</td>
<td>2.1</td>
<td>2.1</td>
<td>2.1</td>
<td>2.1</td>
<td>2.1</td>
</tr>
<tr>
<td>1907</td>
<td>3.1</td>
<td>3.4</td>
<td>2.1</td>
<td>1.6</td>
<td>1.2</td>
<td>1.2</td>
</tr>
<tr>
<td>08</td>
<td>3.0</td>
<td>4.7</td>
<td>1.7</td>
<td>2.6</td>
<td>1.2</td>
<td>2.1</td>
</tr>
<tr>
<td>09</td>
<td>3.1</td>
<td>3.2</td>
<td>1.6</td>
<td>3.0</td>
<td>1.6</td>
<td>2.5</td>
</tr>
<tr>
<td>1911</td>
<td>3.1</td>
<td>3.3</td>
<td>1.8</td>
<td>2.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>2.7</td>
<td>3.4</td>
<td>2.0</td>
<td>2.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>2.3</td>
<td>3.6</td>
<td>2.6</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The Central London Railway was more profitable between 1900 and 1906. But it never paid a dividend of more than 4%.

Source: Garkes Manual, Reports of the London Traffic Branch of the Board of Trade, B.P.P.
reach. Bus competition prevented higher fares. The later
competition of other lines reduced the London's traffic
and reduced profits to a low figure. By April 1903 the Underground
Company was in financial difficulties. £7 m. had been borrowed on
short term profit sharing notes, which had to be renewed.

It is impossible to discuss the demand for tube transport
in London, and the competition of surface transport without considering
the layout of the system. There can be little doubt that it was poor
and that a better one would have been more profitable. The lines
followed the streets. The new tubes connected very badly with the
existing District and Metropolitan lines, particularly around the
northern part of the Inner Circle. Lines were run parallel quite
close to each other. The public utility control of the time prevented
an overall private scheme and the local government of London among
other matters made an overall municipal scheme impossible. Parallel
routes are what one expects from competitive railways. Happily one
piece of proposed competition which would have made the layout even
more unprofitable without being of use to the Metropolis fell through.

In 1902 J.P. Morgan sought Parliamentary powers to construct a tube
railway from Piccadilly to the City and then to N.E. London. This
was to be fed from the west by the London United Trams who were to build

2. See Chapter 9.
a line to Piccadilly. These trams had hitherto fed the Central London at Shepherds Bush and, alarmed at the possible diversion of the trams, the latter promoted a Bill to extend its lines to Hammersmith and then to return via Piccadilly and Charing Cross to the City, making a circle route. Parliament rejected this scheme, but it is not likely that it would have rejected the scheme of Morgan and the L.U.T. This was now only opposed by the Yerkes-District group on the grounds that Morgan's scheme would parallel their lines, running between the existing District and the proposed Great Northern, Piccadilly and Brompton, and Parliament felt that the District railway was not entitled to special consideration as they had not been so mindful of the public interest in the past as to deserve it. However, a dispute arose between Morgan and the L.U.T. as to the representation of their various interests on the management and Speyer Bros., who were helping to finance Yerkes scheme stepped in and got control of L.U.T. by purchasing ordinary shares, thus foiling the Morgan scheme.

The relationship of surface transport with the tubes was unfortunate. Ideally underground and surface transport are complementary. The question whether one should have subsidised the other or not, is not to the political situation of the time. But good planning of routes and stops so that it was simple to transfer from underground to surface transport and vice versa would have raised the demand for transport by reducing the time taken travelling - which is one of the major cost items. Elimination of some competition would have reduced

the costs of the provision of given transport facilities, as competition between a few transport undertakings tends to produce parallel routes with inadequate facilities for transferring from one to the other.

A good example of the benefits of good linkage was shown by the great advantage the Central London Railway derived from sharing a terminus with the London United Tramway, at Shepherds Bush. The two together provided an excellent means of transport from Acton, Ealing and even farther out to the City. Although London's tramways were being electrified and extended at the time the tubes were being built, good connections between the two were rare. Before electrification the trams were scattered in separate units some distance out of the Central area. From 1896 the L.C.C. began to take them over, and from 1900 it began to electrify them and combined the separate networks into two big systems, one north of the Central area and south of the river. The borough east of the County boundary also had their electric trams. Except for isolated cases there was little competition with the tubes. An exception was the Great Northern & City tube, which suffered greatly from the L.C.C. trams. But it was a badly sited tube. Generally tubes and trams occupied contiguous or nearly contiguous areas, and thus the lack of good connections between the two is rather surprising.

But the relations between the tubes and the L.C.C. were poor, and by 1906 both were very short of money. The L.C.C. was unable to complete its plans. This was partly because it was committed to the high cost conduit system, but also because borrowing was becoming more difficult. In 1906 Lord Willby, the Chairman of the Finance Committee,
told the Council that the "policy involved a heavy demand on the money market in the next two to three years. We are already paying a high price for our trams and we shall have to pay a higher price in proportion as our trams are larger ... I hope the Council will not entertain new schemes until this one is finished." A year later the Municipal Reformers won the L.C.C. election on a policy of opposition to L.C.C. public utility schemes.

Central London was served by buses on the surface. The tubes suffered by the appearance, just as they were complete, of the motor bus. In 1905 there were few of them, by 1907 there were large numbers operating in central London. The Central London Railway lost a considerable number of passengers to them, its traffic falling by 14% between 1906 and 1907. The decline was particularly marked in short distance traffic and forced the tube to abandon its standard 2d. fare.

The advent of the electric train and particularly the motor bus led to price cutting, and in 1908 the London Traffic Branch of the Board of Trade reported that almost all operators were making losses. The motor bus operators were doing as badly as anyone; by the second half of 1906 the working costs of the London General Omnibus Co., the largest operator had risen above receipts.

Thus part of the unprofitable operations of the tubes was due to transitory factors, particularly the timing of the introduction of

the motor bus. But part of the unprofitability was due to the competition of different forms of transport in their choice of routes. Better routes and connections between different forms of transport would have stimulated the demand for travel, a demand which was probably inelastic, at least over the range of fares between profitable and unprofitable operation. This competition between buses and tubes was brought to an end in 1912 when the Underground Railways Co. acquired the London General Omnibus Co. The latter had amalgamated with the other big bus operator, the London Road Car Company, in 1903. By 1914 buses and tubes were virtually all controlled by one company.

Both the L.C.C. and the Royal Commission of 1905 wanted shallow subway electric lines, as had been constructed in New York. The easier access to the surface could have substantially reduced travelling time, especially on shorter journeys. The relative cost of subways and tubes was examined by the Royal Commission. The Inner Circle had cost from between £665,000 and £1,283,000 per mile. It used bigger tunnels, some being built for the broad gauge Great Western trains, and the Royal Commission's Advisory Board of Engineers estimated that subways would cost £229,892 to £333,106 per mile. But a large proportion of the cost was the payment of compensation to owners of property disturbed. How costs were divided between street improvements and subway construction, and how much between private and social costs, cannot be known. Also one of the difficulties of the subways was that the cost of damage to pipes, sewers, etc., was unpredictable, as their exact location was often unknown.

The Royal Commission was also impressed by the fast and slow four lane tracks of the New York subway. The average speed on the express lines was 30 m.p.h., double that on the local, and they were correct in seeing that the prime economic point of the underground railway was that it should provide rapid transport. The average speed of the Central London and the City & South London was 15 m.p.h. It is thus arguable that the underground line might have been very much more successful than they were, and that the choice of routes and the type of line used are important explanations of low profitability.

Table 51.


<table>
<thead>
<tr>
<th>Year</th>
<th>Buses</th>
<th>Trams (2 main companies)</th>
<th>Tube (including inner circle)</th>
<th>Metropolitan and District Railways</th>
<th>Other Railways</th>
<th>Suburban traffic on main line</th>
</tr>
</thead>
<tbody>
<tr>
<td>1890</td>
<td>149</td>
<td>191</td>
<td>167</td>
<td>167</td>
<td>167</td>
<td>167</td>
</tr>
<tr>
<td>1898</td>
<td>242</td>
<td>312</td>
<td>10</td>
<td>158</td>
<td>63</td>
<td>180</td>
</tr>
<tr>
<td>1903</td>
<td>290</td>
<td>394</td>
<td>74</td>
<td>153</td>
<td>63</td>
<td>180</td>
</tr>
<tr>
<td>1907</td>
<td>364</td>
<td>586</td>
<td>125</td>
<td>151</td>
<td>88</td>
<td>144</td>
</tr>
<tr>
<td>1911</td>
<td>437</td>
<td>822</td>
<td>134</td>
<td>136</td>
<td>67</td>
<td>145</td>
</tr>
</tbody>
</table>

Season ticket holders are excluded. Bus passengers are those of the two main companies only. Thus suburban railway and bus passengers are seriously underestimated - bus passengers perhaps by a quarter and suburban railway passengers by one fifth to one third. Only a small proportion of the passengers on local railways seem to have been season ticket holders.

For construction of the figures see Appendix F 500.


1. The disadvantage of this system is that it makes the subway hideously noisy. Americans were more willing to pay for rapid transport than the English, and in more ways than in higher fares.
In the provinces the Liverpool Overhead Railways corresponds in some ways with the City & South London. As early as 1852 an overhead railway was proposed to run 4 miles along the docks, but was rejected by the Dock Board despite the strong support of Liverpool merchants. But by 1880 the tramway running along the docks at ground level was overcrowded and other facilities had to be provided for passengers. A tunnel was rejected as too expensive and A.G. Lyster, the Dock Board's engineer, was sent to New York to report on the overhead railways. His report led to the Dock Board asking for powers for a single overhead line, but the Board of Trade insisted it should be a double line. In 1885 the Dock Board proposed a scheme for a double line to be worked by steam at an estimated initial cost of £585,000. By then, however, Lyster was considering electric traction, having been in touch with Sir William Siemens before the latter's death. In 1897 the undertaking was leased to an independent company which was incorporated in 1898 and which in the following year had no difficulty in raising all the capital it required in Liverpool. They decided on electric traction, which was estimated to cost £466,000, a saving of 20% on the steam cost. An electric service with light frequent trains meant the structure could be cheaper. With an electric locomotive car it was not necessary to have a heavy locomotive engine to provide tractive grip. The Manhattan Elevated Railway ran trains of 104 tons fully laden, against 38 tons on the Liverpool overhead. The former took twice as many passengers but the weight per passenger was higher, 43 tons against only 34 tons on the latter. Thus horse power

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1. The above is based on a paper by J.H. Groathead and E. Fox read to the Institute of Civil Engineers, (Elect. 21031, August 1894) and an account in the Electrical Review (Vol. 33, PP 151 - 9, 10 February 1893)
per passenger could be less with the electric system, which could be offset against the higher capital cost of electrical equipments per horse power. Also running costs were less. In 1893 running costs were only 3.7d. per train mile (including drivers' wages, but not other traffic and management costs). This was no more than the power costs of horse trams carrying no more than a quarter of the passengers. But electricity could provide a faster service than steam, and thus receipts could be expected to be higher. The contract for the whole equipping of the line, boilers, engines, dynamoe, rolling stock, motors and signals, was awarded to the Electric Construction Company. They installed everything and operated the service at first, handing over when it was shown to be running satisfactorily.

The railway was successful; the old horse lines along the dock, which continued to run underneath the overhead, had carried 2.5 million passengers per year. By 1898 the overhead railway was carrying 9 million. The initial equipment was somewhat experimental and in 1902 new motor and control equipment was substituted for it. This was built by Dick, 2 Kerr & Co. and designed by S.H. Short, the American manager of their Preston works, incorporating the best American practice. Acceleration was improved. The average speed was increased from 12.5 to 19.5 m.p.h. while power consumption rose only 25%, making it the fastest stopping urban railway in the world.

1. T. Parker. Electrical equipment of the Liverpool overhead Railway. Elect. 2 March 1894. Parker was the engineer responsible, but even if we make a generous addition to his figures costs were still very low.

2. Short came to England in 1893 after very successful work on railway motors in the U.S.
There were two other urban underground railways in this country, the Mersey Railway (Liverpool to Birkenhead) and the Glasgow subway. They contrast interestingly. The Glasgow subway was first proposed in 1887, traction to be by cable. Powers were obtained in 1890 and a consulting engineer appointed in 1893. He invited cable and electrical manufacturing firms to propose ways of working. In 1893, the year after the subway had opened as a cable line, the Contract Journal commented:

"This (proposing ways of working) the electrical contractors seemed very loth to do, while on the other hand, the cable people came forward with all particulars and figures, and entered most fully into the matter. This enabled the engineer to lay before the directors a very complete scheme for cable traction, whereas practically all he could say with regard to electric traction was that certain firms offered to carry out the contract in a satisfactory manner if placed with them. Had the electrical manufacturers come forward in a similar manner, we have a strong feeling that their information and experience combined with Mr. Morton's (the consulting engineer) sound mechanical ideas, and also with the large amount of experience he gained in America on traction plants of all kinds would have enabled him to draw up a specification for electric traction that would have convinced, not only himself, but also the directors."

The Mersey railway was a steam line running from Liverpool under the river to Birkenhead. In 1895 the directors became interested in electricity and sought powers for electric working. Nothing more was done until the electrification of the Birkenhead trains in 1901 started to reduce the Mersey railway's receipts. Then in 1901 a contract was signed with British Westinghouse to re-equip the railway for electric working. The contract was worth £635,303, but only £15,000 was to be paid in cash, the rest being in 4½% perpetual debentures. Westinghouse agreed to provide up to £240,000 in cash should the Mersey Railway Co.

1. Vol. 38, P 156 ff. 26 January 1893. This was not a journal committed to belief in the natural superiority of electrical methods.

2. E.R. Vol. 49, P 549. 4 October 1901.
require it to pay off its debentures so that electrification should not be delayed. If debentures were not paid off Westinghouse was to guarantee interest on them (a possible liability of £17,000). Most of this money came from the Westinghouse parent company at Pittsburg.

Electric working started in 1903. The electrification was a successful piece of engineering. It provided a much better service and more than won back the passengers lost to the trams. In 1900 the railway carried 8.4 million passengers and by 1902 only 6.9 million, but by 1907 it was carrying 11.2 million. Thereafter the figure rose only slightly. But it does not seem to have been a profitable venture. Before electrification working expenses exceeded receipts. By 1904 the company was making a surplus above working costs and this grew. Yet even by 1907 this was only 6.2% of the book value of the cost of electrification. Traffic never seems to have become dense enough.

It was also reasonable to expect electric traction to be used on the suburban routes of main line railways. There was a good deal of interest shown by the railway companies right at the beginning of the century, but the rate of electrification up to 1914 was very slow.

2. E.R. Vol. 52, P 875. 22 May 1903.
3. Excluding season ticket holders.
4. £371,571 at June 1906. It was not given before this. This is only 58% of the sum paid to Westinghouse.
In 1902 the North Eastern Railway decided to adopt electric traction on 40 route miles of their lines between Newcastle and the Coast on the north bank of the Tyne. In the same year the Lancashire and Yorkshire railway announced its intention to electrify 23 route miles of track between Liverpool and Southport. Detailed plans had been under consideration for the previous 12 months and a large number of tests had been made. The London Brighton and South Coast Railway applied for powers for electrical working, the managing committee of the South East and Chatham gave notice of their intention to do so, and the Great Eastern was considering the subject in "all its bearings". The London & South Western told a Parliamentary Committee on a Bill which sought authority to construct various tramways in Surrey and Middlesex that it intended at some future date to convert part of its suburban lines to electric working.

In March 1904 the North Eastern and Lancashire and Yorkshire electric lines were opened. They used multiple unit trains, with d.c. motors collecting current from a 3rd rail at 600 volts, the standard method being adopted for the London underground at the time, developed principally in the United States. The Brighton railway continued in its desire to electrify but was anxious to avoid the live 3rd rail, which it thought dangerous, especially on the complicated tracks over which it

1. 82 miles of single track.
operated in conjunction with other companies. Also they did not want to interrupt traffic during electrification. Commutation above 600 v. with traction motors was very difficult at the time and overhead lines were impractical at this voltage as the cross section of the conductor would have had to be very large. The use of a.c. would have solved the transmission problem but the difficulty was that a.c. motors have poor torque at low speeds, thus being particularly unsuited for traction. The 3 phase motor was better in this respect than the single phase one. It was developed for traction by the Ganz Company of Budapest and used in several installations in Switzerland and Italy. It was almost used by the Metropolitan Railway in London, but otherwise found little favour in this country. A difficulty was that it required 2 overhead conductors. There was also considerable activity in developing a single phase motor for traction. In 1902 Westinghouse at Pittsburg, followed in 1903 by G. Finzi of Milan and the Union Electric Company of Berlin announced that they had satisfactory single phase traction motors. Encouraged by this the Brighton Company asked P. Dawson to investigate the possible electrification of its lines and he reported that the single phase overhead system was satisfactory. The work was put out for tender in 1905 and awarded to A.E.G., who had taken over the Union Co. But it was not until 1909 that the first line on this system, 8½ miles long from Victoria to London Bridge, was opened for traffic. It was quite satisfactory and in 1910 the directors decided to extend its electric lines almost

2. Ibid...
to Croydon. When this was done they had 70 miles of single track working and in 1913 announced that they were to convert another 150 to electric working, thus extending it beyond Croydon to Sutton and Coulsdon, and adding another electrified line from London Bridge to Croydon.

In London the other companies proceeded even more slowly. The London & South Western did not start on any concrete plans for electrification until 1912, when it decided to convert a circular route from Waterloo, running through Wimbledon, Kingston, Twickenham and Richmond.

This involved 73 miles of single track, and was to be followed by another 173 miles so that electric working should extend as far as Guildford. Work began in 1913 and the first part was opened in 1915. The system used was 600 v. d.c. with third rail transmission. Meanwhile the Great Eastern, which handled more suburban traffic than any other main line railway, decided to drop electric traction for the moment. In August 1904 the Chairman told the shareholders that

"In regard to electric traction they had thought it advisable not to undertake new schemes for the present. They were watching the development of that position of the Lancashire and Yorkshire between Liverpool and Southport and he, together with the general manager and five other principal officers of the company, had recently visited France to see whether there was anything to be learnt in regard to the working of the French railways. They had come back thoroughly satisfied that there was nothing in what they had seen ... that would prove of use to the Great Eastern Railway."  

5. Quoted in the E.R. Vol. 55, P 218. 5 August 1904.
In 1906 the London & North Western thought it was time to develop suburban traffic. It thought of electrifying the line from Euston to Watford, but not until December 1912 had they a definite proposal. 79 miles of single track were to be electrified from Watford to Euston. 600 v. 3rd rail d.c. was to be used.

Interestingly, the two pioneers were slow to extend electric working. The only further scheme on the North Eastern was the electrification of a short mineral line in County Durham, from Newport to Shildon, which was opened in 1915. The Lancashire and Yorkshire waited for several years before extending its electric lines out of Liverpool to Ormskirk, and not until 1912 did they decide to electrify the line from Manchester to Bury. On the new line d.c. working was used, with a third rail this time at 1200 v. It was also at this time that the Midland Railway, noted for its efficiency and good management, entered seriously into the question of main line electrification. In 1906 it had constructed a light railway 11 miles long from Burton to Ashby, but this was an inter-urban tramway and not a main line railway. Standard tramway equipment was used. This was a pilot scheme and both Westinghouse and Siemens equipment was used. It was not a line with dense traffic, but the company was thinking of electric traction on much used inter-urban lines, rather than on suburban lines. For longer distances and with less frequent service a.c. was at a comparative

2. Immediately after the 1914-18 War the Company had virtually decided to electrify the main line from Newcastle to York. Amalgamation stopped this.
advantage. The pilot scheme apparently worked well, for the company's engineer, J. Dalziel, told a joint meeting of the British and American Societies of Mechanical Engineers on railway electrification, that main line electrification seemed imminent, being the cheapest way to extend capacity on busy lines.

Thus main line electrification began to be quantitatively important in 1910-14, and looked at from the engineering viewpoint this seems late. It was also late compared with the United States.

To try and explain this one must look at the attitude of the main line railways towards suburban traffic, and how much they might have gained by electrification. Unfortunately the evidence is sparse, but there seems enough for a general outline.

Suburban traffic had been growing since the 1860s, and although there are no statistics, it seems to have been growing rapidly in the nineties. The railways do not seem to have actively encouraged it, as it is doubtful if it was profitable. There is no very good evidence on the latter point. The Great Euston, which had more suburban traffic than any other main line railway, argued that workmen's fares were unremunerative. But this may have been because they wished to resist Parliament's tendency to impose low workmen's fares. This Parliament had done from the 1860s on

in return for permission to penetrate further into the Metropolis. When
the Gt. Eastern had extended its line from Shoreditch to Liverpool Street
in 1864 the Act had contained a clause imposing a 1d. workmen on the
7 - 8 mile journeys from Edmonton and Walthamstow, on trains leaving
before 7 a.m. and returning after 6 p.m. At first workmen's fares
were issued only to manual workers, but soon came to be given to all
passengers at certain hours.

Fares for other suburban passengers were higher, and may have
made suburban services as a whole profitable, but perhaps only just so.
The difficulty with increasing suburban traffic was that because of the
morning and evening peaks it required additions to capacity which were
only utilised at those times. This capacity had to be created by
doubling tracks, extending stations adding to rolling stock and building
more powerful engines. Considering the degree of capital intensity
involved fares do seem to have been low. Raising fares was largely
ruled out. It was difficult to raise any fares at the time despite the
general all round improvement in the service given by the railways.
A high peak hour fare would have been regarded by Parliament as improper
discrimination, and inconsistent with the policy of relieving overcrowding
in the towns by imposing low workman's fares.

Also at this time the railways were investing heavily in
improving what seems to have been their prior concern, main line traffic.

P 350.
Many tracks were doubled, the signalling system was improved, coaches were increased in weight as standards of comfort rose, dining and sleeping car facilities were increased, and stations were extended to deal with denser traffic. These improvements for both main line and suburban traffic caused the railways paid up capital to increase much more rapidly in the 1890s than in any neighbouring decade, and the paid up capital per route mile to rise steeply, particularly between 1894 and 1904.

The attitude of railways generally in the nineties seems to have been a passive one in the face of a rising demand for suburban transport; increased facilities seem to have been provided for a growing number of passengers, but there was no attempt actively to stimulate demand. In so far as suburban traffic was not very profitable and a considerable user of capital when demands on the latter were heavy for other purposes, this is understandable.

The Railways regarded electrification primarily as a means of extending capacity more cheaply than could be done with steam working. In this they were correct; the advantage of electrification was not simply that it might have been a cheaper way to run existing services, but that it could transform the type of service offered in order to meet passenger demand better. The running costs of electric trains were less than those of steam trains, the latter being very extravagant with fuel.

because of the length of time the engine was using coal when stationary, either in station or warming up or when slowing down. P. Dawson estimated that suburban engines were only drawing a load 37.5 of the time that their boilers were alight. But considerable investment in electrifying the track, new rolling stock and power stations were necessary, and it is very unlikely that the returns in fuel saving would have been sufficient to justify it. The great economic advantage of electric traction was that suburban traffic could be greatly increased, and the quality of service much improved, at a great saving in both running and capital costs. In the first place much greater use could be made of existing capital. More intensive use could be made of terminal stations. Steam trains took about 6 minutes of platform time to turn round; electric motor car trains which travelled equally well in each direction would take only 1 - 2 minutes. Suburban traffic had filled to capacity some of the main line London stations by the early years of the century, and its increase would have involved heavy investment in station extensions. Dawson estimated that electrification ought to double the commuter capacity of a terminal. It is interesting to see that in 1911 the South East and Chatham Railway saw electrification only as an alternative to extending Cannon Street and Charing Cross stations. Secondly much more intensive use of the existing track would be made. Electric trains accelerated rapidly and could thus run at higher speeds. On the North


2. P. Dawson, *ibid*.

Eastern and Lancashire and Yorkshire electrification increased average speeds by 30 - 50%. Dawson thought that one could double the capacity of existing track by the investment in electrification. In practice the North Eastern increased its ton mileage by 117%, and the Lancashire and Yorkshire its car mileage by 84%. Increasing the speed of steam engines also required considerable investment. The great Eastern Railway developed the Decapod engine to speed up its suburban services. But apart from the cost of the new engines, their greater weight would have involved strengthening the track and bridges.

J. Dalziel told a meeting of British and American mechanical engineers in 1910 that extra capacity on busy lines could be obtained more cheaply by electrification than by doubling or regrading. Speaking unofficially he said that costs were overwhelmingly in favour of electrifying rather than regrading, for instance, the Midland Company's Derby - Manchester, and Sheffield - Manchester sections. Thirdly the use of reversible multiple unit trains would reduce the number of turntables, siding and other turning round equipment and the space occupied by them. Fourthly because electric motors were ready for immediate service at full power, a smaller aggregate horse power was necessary to run any given service.

The Prussian State government estimated that assuming equal reserves and


2. Ibid...


equal work 36% less electric locomotives were required than would be necessary for a steam service.

Fuel costs were lower per passenger mile, as trains were lighter per passenger, and the thermal efficiency of the electrical methods was much higher than that of the steam. That of the Lancashire and Yorkshire electric trains must have been no less than 5½% against perhaps, 1½% on ordinary steam locomotives. Also higher speed and denser traffic would much reduce other working expenses. On the North Eastern line expenses per ton mile fell from 17.5d. with steam working to 9.0d. with electric working. Speaking roughly the service could be doubled for the same working cost.

In this situation the Railway Companies could only be expected to electrify if traffic increased sufficiently to utilise the extra capacity, and produce an adequate return on investment. In the light of this one can understand the apparently ambiguous attitude of the main line companies. In 1900-03 many of them seemed about to electrify suburban lines. Then the new electric trams began to reduce their traffic. The loss was often considerable. As early as 1902 the Great Western reported that its short distance passenger traffic was declining in London.

1. The thermal efficiency of the power station was 7.5 - 8.25%.
I have assumed that 40% of the electricity generated was lost in the power station, in transmission and in the motors.

Birmingham and Bristol due to the competition of electric trams. By 1907 the London Brighton and South Coast Railway had lost 2 million of its 8 million passengers per annum on the Victoria - London Bridge line to the new L.C.C. trams. By 1909 the number was down another 3 million.

Between 1903 and 1907 five railway companies serving the suburban districts of North Eastern, Eastern and South London had lost at least 34 million suburban passengers, largely because of the competition of the trams. This was about 19½ of their estimated suburban traffic in 1903. By 1909 they had lost another 20 millions.

It was argued that they could always remedy this and capture back their suburban traffic by electrification. Sometimes competition had this result. Merely potential competition was enough to move the North Eastern to electrify. But it was a model railway, in the forefront in adopting most improvements of the time. Competition was also an important factor in the Brighton Company's electrification, for many of its services were short distance ones. The Lancashire and Yorkshire

4. See Table 51 The Companies were the Gt. Northern, the Gt. Eastern, the S.E. & Chatham, the London & S. Western and the L.B.&S. Coast.
5. Reports of London Traffic Branch of the Board of Trade. B.P.P.
6. See Chapter 4 P 140.
was like the Brighton Company, without long distance main lines, and had considerable suburban traffic around Liverpool and Manchester. How much it was directly stimulated by competition is not known but it is worth noting that Liverpool Corporation started electric trams in 1898, and at the same time B.E.T. and Southport Corporation were planning to electrify the Southport and District trams.

But the other companies simply let their suburban traffic fall. Suburban traffic of the Great Eastern alone fell by 24 million passengers between 1903 and 1909, and the South East and Chatham lost 18 million, in the same period. In 1909 the Great Eastern substantially reduced their suburban fares and the fall in their traffic ceased. Electrification was no longer seriously considered. The Great Northern did not lose as much traffic as the Great Eastern. But the pressure of demand on capacity was relieved. In 1905 O.R. Bury, Manager of the Great Northern, told the Select Committee of the House of Commons on the Administrative County of London and District Electric Power Bill that "we feel convinced that .... in as much as our suburban traffic is increasing every day that sooner or later we shall have to electrify ...." In 1907 the Great Northern's suburban traffic began to fall. If, as has been suggested, suburban traffic was not very profitable this attitude is easy to understand.

1. In 1898 B.E.T. bought the Southport and Birkdale trams with intention to electrify. E.R. Vol. 43, P 384. 9th September 1898.
3. Q 2786
Interestingly, the London & South Western which eventually did decide to electrify did not lose much traffic until 1912. Once the loss began it very quickly electrified. The London and North Western never had much suburban traffic and electrification seems to have been undertaken to develop it.

Now we must investigate how much traffic might have increased if electrification had taken place. Unfortunately there are not adequate figures on the experience of those companies which did electrify. Traffic immediately rose. On the N.E. Railway passengers rose 40% between 1903 and 1907. On the Victoria - London Bridge line of the L.B. & S.C. Railway passengers from 8 million to 3 million owing to tram competition, but rose to 10 million on electrification, an overall increase of 25%. Only for the North Eastern is there any financial information. Gross profits (receipts less running costs) on the North Eastern rose from £86,239 for the last half year steam working to £103,201 for the last half of 1905. They would have fallen without electrification owing to tramway competition, and if we had assumed that they would have disappeared and thus the whole of the 1905 gross profit was a return to the investment on electrification, it would have provided a 10% return on an investment of £25,000 per mile of single track. As electricity was purchased from North Eastern Supply Co., this was an attainable figure, but

1. Out of this depreciation would have been 4-6%. £25,000 is roughly equal to the investment per route mile in tramways by 1913, half of which had their own power station. The latter had lighter equipment, but a greater traffic density.
unfortunately no information is now available on the actual cost of
 electrification. But it would not have provided a big return.

The immediate increase in passengers upon electrification was
probably barely enough to justify it. The crux of the matter was
whether a better suburban service would bring a long term increase in
traffic as more people were induced to move to the outer suburbs. In
this respect results were disappointing. On the North Eastern passengers
rose slowly after the initial increase. In the second half of 1903,
the last year of steam working, they were 2.8 million p.a.; in the first
half of 1905, 3.5 million, and by the first half of 1910 4.1 million.
After 1912 they did begin to increase more rapidly and in the first
half of 1914 reached 5.4 millions. No attempt was made to electrify
the lines on the south bank of the Tyne until well after the 1914 - 18
war, which suggests insufficiently high density of traffic to make
electrification really profitable. Passengers per electric train mile
were only 6.0 in 1905 & 6, and 6.6 in 1907 & 8. There are no figures
concerning the Southport - Liverpool line, but the fact that the
Lancashire and Yorkshire waited until 1912 before starting suburban
electrification near Manchester suggests the same story.

But both where suburban lines were electrified and where they
were not, the traffic figures show the effect of electric tram competition.
Because this either reduced traffic or reduced the rate of its expansion,
it slowed down suburban electrification. Only very fast urban growth
would have changed this. The rate of growth of the big towns however
slowed down after 1903, London is a good example. When building was
booming in 1903 the Royal Commission on London Traffic was told of the
large increases in suburban population consequent on the provision of
better transport. The population of areas served by the Great Eastern
suburban services had grown substantially and was clustered round the
stations. Many areas served by the District Railway had doubled their
population in the preceding 20 years. In the late nineties this
movement to the London suburbs seems to have accelerated. The population
of the area served by the London United Tramways rose 26% from 1899-1904.
But there seemed to have been considerable overbuilding by 1905. Thus
further building was unlikely and it is not likely that in these
circumstances better suburban services would have been enough to stimulate
it.

Evidence on the relation between transport facilities and
building is inadequate, and thus conclusions can only be tentative.
However an examination of the question from the viewpoint of transport
electrification, both of transm and suburban railways does suggest that the
main line of influence in the short run was that of house building on the
demand for transport, rather than the other way round. Better transport
seems to have been permissive rather than rapidly stimulating.

IV

Electric traction and electric lighting were to some extent
complementary. As J.W. Southern told the Select Committee on Municipal

3. ibid., Evidence of J. Clifton Robinson. Qs 24776 - 24780
The district was Chiswick, Ealing, Acton etc.
"If you have to send electricity through a district for your trams, you may as well use it for your lighting and for supply generally." The same generating plant and the same transmission mains could be used for both lighting and traction. The distribution systems had to remain separate for the usual tramway pressure, 500 v., was too high for general supply. The exception was that street lamps could be run from the tramway overhead wires, and thus was very convenient as arc lights were the best way to light a street important enough to have a tramway. Yet at first traction and lighting systems were quite separate from each other. In 1897 there were 11,617 horse power electric tramway and railway motors in operation, excluding those on the City and South London Railway. All were driven by electricity generated in their own tramway power houses. The City and South London Railway also had a power house. By 1902 there were 164,685 h.p. of motors supplied from public supply stations, but another 182,600 h.p., again excluding the City and South London, supplied from separate power stations. Electric railways bought very little from public supply stations. All of them had their own power stations except the North Eastern and the London Brighton and South Coast. The available information is summarised for 1903, 1907 and 1912 in Table 52.

2. Electrical Trades Directory.
3. ibid.
### Table 52.

Source of supply of electricity used by electric trams and electric railways.

<table>
<thead>
<tr>
<th>Year</th>
<th>Tramways</th>
<th>Electric Railways</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Generated in own power station</td>
<td>Purchased from public supply</td>
<td>Generated in own power station</td>
</tr>
<tr>
<td></td>
<td>m KWh</td>
<td>m KWh</td>
<td>m KWh</td>
</tr>
<tr>
<td>1903</td>
<td>107.7</td>
<td>103.4</td>
<td>35</td>
</tr>
<tr>
<td>1907</td>
<td>204.1</td>
<td>209.4</td>
<td>198.9</td>
</tr>
<tr>
<td>1912</td>
<td>347.4</td>
<td>238.7</td>
<td>214.5</td>
</tr>
</tbody>
</table>

Figures are on calendar year basis for all electric railways and electric trams owned by companies but on year ending 31st March in following year for municipal trams.

1. Residual.
2. 12.4 m KWh cannot be allocated.
3. No more than an extremely rough estimate is possible. The generation of the Central London Railway in 1904 is known and the generation for other lines is based on this and the number of passengers they carried compared with the C.L.R.
4. Includes estimate for Brighton Railway.

For methods of calculation see Appendix P.499.

**Sources:**
- Board of Trade Returns relating to tramways
- Board of Trade Returns relating to electric railways
- Calculations from Gono's Manual
- Select Committee of House of Lords on Administrative County of London Electric Power Bill
- Electrical Trades Directory.
There are several reasons for this. In the first place when electric traction started it was on a big scale compared with existing lighting loads. In 1893 91 million kWh were sold by public supply stations, virtually all for lighting. By 1903 traction was using 246 million kWh. Thus plant would have had to be extended very considerably. In big cities the trains required a great deal of plant; Glasgow for example, contemplated a tramway power station of 10,000 kW. There was no gain at the time in combining one of this size with the lighting plant as all possible economies of scale were already exploited. The London Underground railways built at Lots Road a power station of 44,000 kW capacity, which remained the biggest power station in the country up to 1914. But after Merz had shown the advantages of really big power stations in 1904 - 5 the argument is no longer valid, and economies of scale would have been possible when both general supply and tramways were being extended. As for the transmission lines, tramways and lights were initially in the centre of towns, and economies of scale could only have been achieved when both were extended to the suburbs.

Secondly, in the nineties tramway generators were of different design from lighting generators. This was partly because of the different characteristics of the load. When there were only a few trams, large sudden variations in the load were produced when each car started. Ordinary lighting generators were not designed for this type of service. Again this argument became irrelevant in the early 20th century when the number of cars in each tramway rose to produce an even load, when generators had increased in size so that variations were small compared
with output, and when the design of generators had changed so that
they were designed for big variations which could occur on power circuits.
But it was partly because electric traction in the late nineties used
American methods and its equipment was designed by American engineers.
They were used to large slow speed generators, and not the small high
speed machines used by English lighting stations, and were probably
correct in thinking that the small fast English generators were too
flimsy and likely to break down for heavy traction work. The American
type tramway stations were cheaper than the average English lighting
stations. The latter were costing £40 - £50 per KW at the end of
the nineties; the power house of the Central London railway cost £34
per KW. H. F. Parnell told Glasgow Corporation that a 10,000 KW
power station would cost £32 per KW. Lots Road cost under £28 per KW.
But the average English figure includes a number of small stations. The
bigger public supply stations at the turn of the century cost much the
same as the tramway power houses. The former were however on American
and Continental lines and most English consulting engineers who would
have been responsible for designing plant for extending most public
supply stations for tramway supply would have continued with the usual

1. Administrative County of London Bill, House of Lords Committee Q 2568
   1905.
3. From Underground Electric Railways Ltd. accounts.
   The cost here includes transmission mains. The power station
   may have cost as little as £20 per KW at a guess.
English practice. Thirdly there is the pricing policy of public supply stations. They often seem to have seen a tramway load as a way to subsidise electricity for lighting, as a way to increase the aid which electric supply was often giving to the rates, or a way to increase profits. In the late nineties they thought of 3d. a unit as a normal charge for tramway current, but the trams could generate for themselves at a little over half that price. The situation was aggravated by the cases where either the trams or electricity supply in a town was run by the corporation and the other by a company. Thus Bristol Corporation tried to make the purchase of current from the electric lighting station a condition of permission for the Bristol Tramways Company to run trams in the streets of Bristol. The Company refused; H.P. Parshall considered they could generate more cheaply themselves, and that the Corporation's lighting machinery was not suitable for a traction load. Relations were bad for other reasons, and even at a cost of production price the Company would have been unlikely to want to buy current. Similarly Corporations would not want to buy current from utility companies which they tended to regard as monopolies seeking opportunities to exploit the public. It was understandable that Corporations like Preston and Reading should build their own tramway power houses. Antagonism went very deep in some


cases, particularly when enthusiasm for municipal trading was at its peak. It is only in such terms that one can explain the action of Newcastle Corporation in building their own tramway power house, when current could have been bought from N.E.S. Co., at a price almost certainly below the Corporation's cost of production. But separate tramway power houses were not always due to antagonism between municipalities and companies. In 1907 we find Glasgow, Leeds, Sheffield, Leicester, Hull, Portsmouth, Huddersfield and Birkenhead with both general supply and tramway power houses. In Glasgow when electrification of the trams was first decided upon, the tramway committee's decision to build its own power house started a conflict between the tramway and electric lighting committees which was even more violent than that between Company and Corporation in Bristol. As at Bristol, the tramway side won, again supported by the opinion of H.F. Parshall. In the majority of municipalities supply came from the Corporation's lighting station. In the year ending March 1908 municipal trams bought 176.1 million KWh, and generated 148.7 million KWh, but of the latter quantity only 71.7 million KWh was in towns where the Corporation had a lighting station. The accounting price fixed for the transfer of electricity between the two departments fell with this municipal controversy to between 1d and 2d, where it remained. Once the separate traction power station was built it was rarely worth changing the situation. The demand for electricity

1. E.R. Vol. 43, P 597. 21 October 1898
2. Possibly up to 3% less.
for trams, rising from 316 million KWh in 1905 to 630 million in 1913, could best be met by extensions to the tramway power house, or by substituting new generating plant with a greater output but occupying the same space.

A potential loss with separate tramway and lighting power stations was that if the peak loads of each did not coincide, more plant would be needed than if there was one station, or if the two were connected. The extent of peak demand diversity is not known as it does not generally seem to have been studied. But the loads overlapped, both with a peak in the early evening usually between 5 and 6 p.m., and there is not likely to have been very much diversity. It is not, however, safe to assume that the diversity of demand was not worth consideration, as seems often to have been assumed in contemporary discussion.

Charles Merz argued that the failure of London electricity supply to exploit potential economies of scale was a great hindrance to railway electrification. He considered that cheap supply would stimulate the latter and estimated a very large sale of electricity from his proposed power stations for traction. He was supported by evidence from the Great Northern Railway. O.R. Bury, its manager, told the Select Committee of the House of Commons on Merz’s Bill that if they could take a cheap outside supply "it would remove one of the chief difficulties we have in the way of adopting electric traction, because the power station is of course a larger percentage of the total cost in changing the method of traction ... sooner or later we shall have to electrify and it would hasten our decision with such a power house as is now suggested at our
disposal”. Electric power costs would have been about 25% of working costs, and even if halved, as Merz promised, it is not by any means certain that it would have made a crucial difference. The reduction in the amount of capital that had to be found for electrification was probably more important, because of the heavy demands on railway capital at the time.

It is difficult to know how much weight to give to this as railway companies seemed to prefer their own power plant. Philip Dawson told the Committee of the Lords on Merz’s Bill

"I am consulting electrical engineers to the London, Brighton and South Coast Railway. I have therefore had to examine the question very carefully as regards the cost of electrification and cost of energy for traction purposes and I have reported on them at length. In fact at the present moment we have asked for tenders for the purpose of electrifying a portion of our system experimentally. I know therefore at what price we could produce our own energy if we required it on any scale, and it would certainly not pay us to consider purchasing power; and even if there were prices approximately equal, a railway company would never consider taking power from an ‘outside source, and running the possible risks which might be involved in the stoppage of a supply from an outside source over which they had no control.”

Ironically enough, the Brighton Railway was one of the only two which bought all its electricity for traction from the public supply, but other late electrification schemes, the London and North Western and the London and South Western planned to build their own power houses.

1. House of Commons Committee on Administrative County of London and District Electric Power Co. Bill. Q 27781 & 86.

2. Mersey Railway figures - the only ones apart from the untypical District Railway.

3. Q 5273.
Yet Merz's plans for London failed to materialise.

Thus there is unfortunately not enough evidence to come to any firm conclusion; cheap power might have hastened the electrification plans of 1910-11 in London, but we cannot say more.
Chapter 6.

Electric Power.

By 1907, when for the first time overall figures are available, more electricity was used for electric power than for either lighting or traction. Statistics are incomplete and imperfect but estimates suggest that 2,385 million KWh were used for all purposes in that year. Between 1,000 and 1,400 million KWh were used for power, that is 40 - 60% of the total. Most of it was generated by users. Mining and manufacturing, the principal users of electric power, used 1256 million KWh of electricity in 1907. Only 283 million KWh had been bought from outside. By 1912 power was still more important among uses of electricity. In that year something like 4,146 million units were used; between 2,400 and 2,800 million, 60 - 80% were for power.

The use of electricity for power was in 1907 a very recent development. In principle the electric motor is a dynamo working in reverse, converting electric into mechanical energy. This had been known from 1873 onwards, but for some years no commercial use had been made of electric motors. Apart from traction use scarcely any electric motors were in operation in the 1880s. The early nineties saw a few motor installations. By 1894 the Electrical Review was able to point to

1. See Chapter 3, Table 25.

2. It is said that the use of a d.c. generator as a motor was discovered accidently at an electrical exhibition in Vienna in 1873. See Fleming, op.cit., P 138.
electric driving in the works of Siemens Brothers, the Electrical Construction Corporation and Howard and Bullough's, but to no other large installations. There were also a number of small installations, each with a few motors. Two years later there were enough users of electric motors for it to be clear that in certain cases electric motors were cheaper than mechanical drives. Electrification at this stage seems to have been concentrated on the North East. As D. Selby Bigge told the Cleveland Institute of Engineers in November 1897:

"In no part of the country has the progress made in electric driving been so marked and rapid as upon the North East Coast, in fact it may truly be said that the engineers of the Middlesbrough, Hartlepool and North East Coast districts have, to a very large extent, been the pioneers of the system in this country."

What motors there were then were d.c. ones. Meanwhile the a.c. motor was being developed abroad and this was to prove a great stimulus to factory electrification. In 1883 J. Hopkinson showed that it was theoretically possible to run alternators in parallel. He argued that they would control each other and keep in phase if started in step. It followed that from this that an alternator could be used as a motor. In the eighties however only single phase a.c. was used and the single phase motors of the time when they were heavily loaded could easily get

1. Manufacturers of cotton spinning machinery.
out of step with the generator and would then stop. They then had to be
restarted in step. Improvements in the a.c. motor took two directions;
one, improvements in single phase motors and the other, the development
of multiphase motors.

A d.c. series motor could be used on 1 phase a.c. circuits,
although not as satisfactorily as on d.c. circuits. In 1889 Elwhi-
Thomson developed a repulsion a.c. motor. It was not very satisfactory
owing to sparking at the commutator and a low power factor. However the
repulsion and compensated series motors were combined in a commutator
type induction motor. This worked well enough but was still inferior to
the d.c. motor as the cost per horse power was higher and the bulk greater
than with d.c. motors. There were often difficulties in starting as the
a.c. motor had poor torque at low speeds. The d.c. motor on the contrary
performed very well over a very wide range of speeds. Much of the work
on the single phase motor was inspired by the hope that motors could be
developed for the single phase a.c. lighting circuits. Unfortunately
these motors would only work properly at a low frequency, 40/v and below,
while most of the lighting stations had frequencies well above this;
usually ranging from 80/v - 140/v. Under 40/v the lights flickered and arc
lamps were particularly unsatisfactory. Thus the bottom frequency limit
for lighting was the top limit for power. For these reasons one could
expect few a.c. lighting stations to be able to develop a power load. A
factory putting down a system of electric drive complete with generating
plant would naturally choose d.c. as it was cheaper in first cost and more
satisfactory in operation.

The only extensive use of the single phase a.c. motor was in traction. This involved work on a motor specially designed for traction.

It was used on several railways including the Brighton railway, but the great weight of the motors compared with d.c. traction motors and their inferior torque at low speeds told against them. It proved simpler to raise the operating voltage of d.c. motors by improvements in commutation.

Polyphase motors appeared to be more complicated at first but eventually were shown to have great advantages not only over single phase a.c. motors but over d.c. motors for some applications, namely those where constant speed operation was desirable. The use of 2 and 3 phase alternating currents to produce a rotating field occurred independently to Professor G. Ferraris, Nikola Tesla and Von Dovilo Dobrowolski between 1885 and 1888. Ferraris published his work in March 1888, and in May of the same year Tesla showed a rotary motor running with four wires.

Various improvements and modifications were introduced by Bradley, Haselwander, Westrom, Elihu Thomson, Dobrowolski, C.E.L. Brown and others. The first practical demonstration of 3 phase power was with the Frankfurt-Lauffen plant. This showed beyond doubt that a.c. could be used for power and all the advantages of voltage transformation could be used for motors as well as lighting. The first large scale power scheme with

1. See Chapter 5, P 223.
4. Bradley was an American.
5. See Chapter 3, P 100.
polyphase a.c. was the Niagara Falls scheme opened in 1895, demonstrating that polyphase power was not only possible but in many cases commercially desirable. The Niagara scheme used 2 phase a.c. This is inferior to a 3 phase, the latter being cheaper in first cost and giving a more even turning motion. It seems to have been adopted because of the distribution complications of 3 phase current, principally the difficulty of balancing the load on a 3 wire system.

Thus by the middle of the nineties there were two competing systems of electric motors, d.c. and polyphase a.c. But although competing over a range of uses they each had relative advantages in certain uses. The d.c. motor was a better variable speed one and had high starting torque. Thus for driving cranes, lifts, hoists and traction it was the obvious one to use. The a.c. motor was able to maintain a more constant speed over a wide range of loads. Thus it was particularly useful for driving lathes, looms, spindles and similar pieces of machinery. The 3 phase system however, when developed, had one very important general advantage over the d.c. system. The induction motor itself was very simple and robust. It had no commutator, and thus could not spark. It would operate without difficulty under much dirtier conditions than could the d.c. motor, and consequently for similar operating conditions required very much less maintenance. A large number of running difficulties with d.c. motors were due to commutation and to have designed a motor without a commutator was an enormous advantage.

1. See H.C. Passer, *op.cit.* Chapters 18 and 19, for the story of the development of the a.c. motor in the U.S.A.
English electrical engineers had taken no part whatever in the development and improvement of a.c. power during the nineties. Their attitude was well described by the Electrical Review in 1894:

"The polyphase system is highly praised by those who know it best, and although it has not yet in this country, met with the same open hostility through which the single phase method successfully passed, it has been treated even more shabbily by indifference, a sort of passive resistance even more deadly than active war ... In other countries, polyphase machinery has already become a catalogued part of every manufacturer's trade".

When polyphase a.c. came up for discussion at engineering meetings it was dismissed as an unimportant, and not very satisfactory development. This attitude shows well in the report of the remarks of Alexander Siemens at the I.E.E. during the discussion on A.B. Snell's paper on the "Distribution of power by a.c. motors".

"English engineers should not be too much blamed for holding back on this question of a.c. They were, after all, a body of practical people who had to apply science to everyday life, and that which had to a great extent to govern them in what they did and what they investigated was the eternal question of £ s.d. His firm had been very much interested in rotary (polyphase) motors and had worked a good deal in that direction. They had not done so much in England because it was obviously unnecessary to go to an extra set of experiments whilst they had the experience of Berlin (Siemens and Halske) at their disposal. Whenever they had to work out a problem for transmitting power to a distance they gave the exact problem to their Berlin house and asked them to work it out according to the rotary system, and up to the present they had not had one instance in which they could not carry out such a problem just as well by either d.c. or the ordinary a.c. machines. .... They must wait until they had got a thoroughly practical a.c. motor which they could use on the ordinary mains and then they would use it".

As the ordinary a.c. mains were single phase the last sentence is a stronger rejection of the value of polyphase power than it at first

sounds. Also, as public supply mains were in the centre of large towns only, it implies a dismissal of the large potential market in isolated electric power transmission schemes for large factories.

Possible infringements of the Tesla patents of 1888 were sometimes given as a reason for the lack of interest in polyphase motors. The Electrician argued in 1895 that it was not entirely due to ignorance on the part of British manufacturing firms, nor even to a natural conservatism tinged with the feeling that the advantages of polyphase motors have been somewhat overstated.

"The cause of the delay in this country has ... to a large extent been due to the uncertainty that exists as to what claims would have been made by the owners of certain patents and as to the ground they would consider covered by such patents".  

The Tesla patents were very wide and English companies had suffered from several infringement cases in the 1880s but this cannot be enough to explain the British attitude. General Electric in the United States was able to find ways around the patent difficulties, and the big Continental firms do not seem to have been deterred in this way. There seem to have been no attempts in this country to find a method of using 3 phase power without infringing the patents quite apart from the fact that there was general doubt as to whether the Tesla patents would have been sustained in the courts because of the parallel work of Ferraris and Dobrowolski. The Electrical Review confessed it could think of no good reason why polyphase power was neglected in this country lamenting that "its advocates (those of polyphase) are enthusiastic and

1. **Elect. Vol. 35, PP 262-3.**
make great claims for it, have spent time, money and brains on perfecting it, and yet the ordinary engineer jogs along the beaten path quite oblivious to all their efforts."

Such was the position in 1893-5; British engineers were clearly not in the vanguard of engineering developments. But in 1897 attitudes were still the same. In the discussion at the Society of Arts on W.B. Esson's paper on the "Transmission of power to long distances by alternating currents of electricity" Alexander Siemens again argued the superiority of d.c. over a.c. power, for, it seems, all purposes. At the same meeting W.M. Morday, the Brush company's chief electrical engineer, with ten years successful work on the design of a.c. machinery behind him, said that he was sorry not to be able to speak from experience with regard to polyphase motors.

The first polyphase power installations came in 1897. The West Hartlepool's firm of Thomas Richardson & Sons, who had not hitherto been involved in the manufacture of electrical apparatus, decided to install a 1250 h.p. 3 phase power system in their works. The machinery was bought from Brown-Boveri. They also made arrangements to start manufacturing 3 phase plant under licence from Brown-Boveri. C.F. Higgins, formerly chief assistant to the latter was sent over to superintend Richardson's electrical department. The patent problem was easily surmounted; a licence was obtained from Westinghouse to manufacture under the Tesla patents.

In 1897 Brown-Boveri had made two other installations of polyphase machinery in Britain, one in Edinburgh and one in Glasgow, involving 130 and 100 h.p. respectively. 1897 also saw the first G.E.C. polyphase installation in the Liverpool Grain Storage Company's warehouse. This seems to have been the first in this country to combine lighting with 3 phase power. G.E.C. was not an established firm manufacturing electrical machinery, it was primarily a wholesaler of electrical goods, although it had made light bulbs from 1893 onwards and also made telephone equipment and light electrical apparatus. But it made an agreement with Maschinenfabrik Oerlikon to manufacture polyphase plant under licence.

In 1897 there was one, possibly two more very small polyphase installations making five to six in all. A year later there were more; the Electrical Review stated that "every week we hear of fresh advances in the polyphase line in England on the part of Continental and American makers". Yet relative to other countries there were very few, for it continued "Polyphase work has become almost universal on the Continent since the famous Frankfurt-Lauffen installation; whilst on the other hand it is yet hardly thought of in England". Not that this worried English manufacturers. At the British Association in 1893 A. Siemens told Section G that in nearly all cases d.c. power was to be preferred. In the

4. E.R. Vol. 43, P 377. 9 September 1898.
discussion of H.F. Parshall's paper on the "Economical Transmission and Distribution of Electricity from a Distance" at a Conference of the Institution of Civil Engineers in the summer of 1899, T. Parker said that he himself thought that there was no need to use 3 phase currents, as his firm were quite prepared to build d.c. machinery up to 2500 V and he thought it would not be difficult to build them for 5000 V.

In a paper to the Birmingham section of the I.E.E. in 1901 W. Wyld gave details of 16 polyphase installations aggregating 4,580 KW. The list is probably almost complete and shows the very small amount of polyphase power used at the time. Thereafter English firms began to take up the manufacture of polyphase plant and in 1902 the Electrical Review was able to say that "slowly but surely, the interest taken by electrical engineers in this country in polyphase working is increasing.

The English manufacturers advocated d.c. motors in preference to a.c., but were scarcely very enthusiastic about the former. It was the mechanical rather than the electrical engineers who were ardent advocates of the electric motor. It was before the mechanical engineering societies that the results of electrical driving were published. The Electrical Review commented in 1896

"Although the electrical engineer is occasionally enthusiastic on the subject of electric motors he has for the most part neglected it. There are of course numerous instances of electrical engineering firms demonstrating in their own works the capabilities of the electric motor; but one is forced to the conclusion that they are not active enough in setting forth the merits of electrical driving".2

1. E.R. Vol. 44, P 1014. 23 June 1899. Computation was very difficult with high voltages. It does not seem likely that Parker's claim could have been sustained in practice.

Mechanical engineers often wanted to find out about the merits of the electric motor, and sometimes had to go to the Continent to get an answer.

English electrical engineering firms thus waited for a demand for motors. That is to say, they waited for an increase in demand. For at a time when innovations were being made resulting in lower initial costs of electric power transmission systems, and in lower working costs because of greater reliability, output could have been much increased by an active policy of innovation on the part of English manufacturers. Demand, moreover, cannot in this situation be considered apart from the activities of manufacturers. In the nineties potential users had little knowledge of the electric motor. Results of the working of electric motors were published from time to time, but could only give a general guide to possible users about the advantages of electrical power transmission to them. All lamps were much the same and produced a fairly simple commodity, light, but turning motion could be used in a vast variety of ways. The driving of cranes, steel rolling mills, machine tools and coal cutters, posed an array of particular problems, whose common elements might be few. Before users could know whether it was worthwhile to apply electric motors for these purposes careful consultation was necessary between possible users and motor manufacturers. Lack of initiative on the part of the latter would lead to a much lower demand than might otherwise exist. The power unit was often an integral part of the machine. Thus close co-operation was required between the manufacture of machinery hitherto powered by mechanical means and the
makers of electric motors. In many cases this would be more important than consultation with final users, but initiative by the motor manufacturers would have the same effect of increasing demand.

The behaviour of English electrical manufacturers is only a part of the explanation for the slow adoption of electric motors in England. It partially explains the slow growth of knowledge of the value, potential and actual, of electric motors; where the necessary knowledge was principally of a variety of possible practical applications it would not spread rapidly over long distances. It partially explains the high first cost of electric power transmission schemes; British plant was expensive, and Continental plant had to pay higher transport costs. These transport costs were particularly high in the nineties because the manufacturers often had to erect, or supervise the erection of, plant. When Continental and American firms had no permanent representatives in this country total transport and erection costs could be high.

The entry of Continental and American firms into this country greatly stimulated the introduction of electric power. This occurred in several ways.

Firstly, there was the formation of selling firms in this country. In the middle nineties A.E.G. incorporated the Electrical Company as their English sales agents. Westinghouse formed British Westinghouse for the same purpose and General Electric used British Thomson-Houston as an outlet for their products. B. T-H. and Westinghouse developed traction equipment as their chief product as their
sales expanded in the late nineties. But both G.E. and Westinghouse were manufacturing non-traction motors.

Secondly, there was the granting of licences to English firms not in the heavy electrical equipment business, Brown-Boveri to Thomas Richardsons & Sons and Oerlikon to G.E.C.

Thirdly, there was the building of three new large factories to manufacture electrical plant just after the turn of the century. Both Westinghouse and B. T.H. decided to begin manufacture in this country, and Dick, Kerr & Co. decided to begin the manufacture of electrical equipment. By 1902, these three factories had largely captured the market for heavy plant. The English firms did not manufacture very large plant and the optimum size of power station plant was sharply increasing at the time. Firms like Crompton and Mather and Platt decided to abandon the manufacture of power station plant. As Crompton told a Select Committee of the Lords in 1905,

"..... two years ago demand for small generating plant closed up ... consequently all the machinery that we used for manufacturing the smaller class of generating plant seemed likely to remain idle, and we therefore went completely into the question of turning out motors in very large quantities and putting down extra special machinery for that purpose".1

Also the American firms were large scale manufacturers of motors.

Lastly the peak of a strong boom in the sales of electrical equipment in Germany was reached in 1900. A sharp recession followed and German firms started to export plant at very low prices.

The result of all this was that motor prices fell dramatically

at a time when the advantages of electric motors were becoming fairly widely appreciated. Crompton before a Select Committee of the Commons quoted as an example the fall in the price of 10 h.p. motors from £60 - £65 in 1901 to £30 in 1905.

Demand seems to have been elastic in these circumstances and the substantial adoption of electric power dates from the years 1902-4.

Some confirmation of this pattern of development is provided by figures of the sale of electricity for power by public supply stations. Unfortunately no figures at all exist for isolated installations. The latter were much more important and there are several reasons for supposing that the timing of adoption of electric power when isolated generating plant was used was different from that when supply was taken from the public mains. Also the figures for supply of power from the public mains are incomplete. An important deficiency is that where a supply undertaking gave figures of the electricity it sold for power it usually only did so when such sales had become substantial. As the figures for the first few years are missing, indexes of output based on those undertakings with good figures differ from those based on estimates of the power sales of all undertakings. For example an output index (1907 = 100) based on those undertakings with figures going back at least to 1905 will omit firms which started selling electricity for power perhaps as early as 1904 but giving no figures until 1906 or 07. Such an under-

taking may individually have been of little importance, but there were a large number of them. On the other hand, if we included all power figures before 1907 this will omit the early years of power sales for some, perhaps many undertakings. Unfortunately we can only use crude techniques of extrapolation to estimate the missing figures (where we may think figures are missing). Table gives output indexes on different sets of figures. C is probably the best, but half the aggregate is estimates which individually have a possibly wide margin of error. That the correspondence of estimated sales for 1907 is quite close to the most probable figure of actual sales does however suggest that the aggregate is not far off the mark.

Table. 53.

Sales of electricity for power from public supply stations

1907 = 100

<table>
<thead>
<tr>
<th>Year</th>
<th>A (Undertakings with good figures going back to at least 1902)</th>
<th>B (Undertakings with good figures going back to at least 1905)</th>
<th>C (All undertakings, includes numerous estimates)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1900</td>
<td>10.4</td>
<td>4.8</td>
<td>8.9</td>
</tr>
<tr>
<td>01</td>
<td>16.6</td>
<td>7.7</td>
<td></td>
</tr>
<tr>
<td>02</td>
<td>25.2</td>
<td>11.6</td>
<td></td>
</tr>
<tr>
<td>03</td>
<td>37.2</td>
<td>17.2</td>
<td></td>
</tr>
<tr>
<td>04</td>
<td>49.8</td>
<td>33.9</td>
<td>23.8</td>
</tr>
<tr>
<td>05</td>
<td>62.9</td>
<td>50.6</td>
<td>37.1</td>
</tr>
<tr>
<td>06</td>
<td>78.3</td>
<td>74.2</td>
<td></td>
</tr>
<tr>
<td>07</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
</tr>
</tbody>
</table>
Thus at least half of the motors driven by purchased electricity in 1907 were installed after 1905, and all but 10% after 1902. It is likely that a higher proportion of motors driven by electricity generated by the user was installed before these dates, but it is impossible to say how much higher.

Any attempt to measure the extent of electrification runs up against a conceptual difficulty. The most obvious method is to measure the brake horsepower (b.h.p.) applied by electric motors to machinery and that applied by steam engines, shafting etc. The problem arises from the fact that in the early days particularly, group, rather than individual electric drive was used. Electric motors were usually used to drive a section of shafting which drove several machines. As electric motors became cheaper they were used more and more to give individual drive. But up to 1914 fractional horse power electric motors were generally much too expensive, and at least up to 1905 sizes below 10 h.p. were rarely used.

Despite this difficulty I have attempted to measure electrification. My measure takes the aggregate horse power of electric motors used and compares this with the total amount of power of all types. Total power is derived from the total engine power less an amount used to drive dynamos, plus an estimate of electric motors driven by those dynamos, plus an estimate of motors driven by electricity purchased from outside. Power applied electrically includes group drive and individual drive indiscriminately. Thus the tendency towards individual drive which indicates a greater degree of electrification, is not revealed.
In 1900 the proportion of motive power applied electrically must have been almost negligible. By 1907 something like one ninth of the motor power applied in mining and manufacturing was driven electrically. Five years later it had probably risen to about a quarter. Electrification of factories continued, and by 1924 about half the motive power used was electrically applied. Such figures cannot be precise, especially for 1907, when they have to be constructed from partial figures of electricity generated by factories, and from probably incomplete figures of motor connections to public supply stations, and for 1912, when the Census was only partial. Also for all three years figures are only available of engine power installed in factories and this will differ from motor power applied to machines, because of transmission losses and diversity. These two would offset each other, and it has been assumed for Table 54 that they simply cancel out. There is, however, no evidence to suggest that this is, or is not, the correct assumption to make. Thus margins of possible error are high. An attempt has been made to suggest likely percentage errors.

A striking result of these calculations is that the total amount of power applied in non-electrical ways, mainly through mechanical methods like belting, and shafting, does not rise between 1907 and 1924. This does not mean that the growth segment was filled by the introduction of electric motors. Between 1907 and 1924 most of the non-electric power transmission would have had to be replaced if electricity had not existed. W. Hoffmann presents evidence suggesting that this type of
TABLE 54.

Motor power in manufacturing and mining (excluding non-ferrous metals)

<table>
<thead>
<tr>
<th>Year</th>
<th>Motors driven by electricity purchased from outside (000 h.p.)</th>
<th>Motors driven by electricity generated on the premises (000 h.p.)</th>
<th>Motors powered by non-electrical methods (000 h.p.)</th>
<th>Total motor power (000 h.p.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1907</td>
<td>356 (+ 10.) - 15.</td>
<td>565 (+ 15.)</td>
<td>7001 (+ 15.)</td>
<td>7922</td>
</tr>
<tr>
<td>1912*</td>
<td>671 (+ 20.)</td>
<td>1126 (+ 20.)</td>
<td>6029 (+ 20.)</td>
<td>8026</td>
</tr>
<tr>
<td>1924</td>
<td>4158</td>
<td>3032</td>
<td>7100 (+ 15.)</td>
<td>14,290</td>
</tr>
</tbody>
</table>

* 1912 Census was only of establishments employing > 5 persons. It may fall short of a total figure by as much as 20%, but probably not by more than 15%.

Sources: Calculations from the 1924 Census tables and the Electrical Trades Directory. For details of method and assumptions used see Appendix. P 502.
plant had a life of about 20 years. Unfortunately we do not know when the 1907 power equipment of industry was installed. It is however possible to arrive at some idea of how much might have been scrapped between 1907 and 1912 and 1924. Let us assume that all the equipment in 1907 had been installed since 1887, and furthermore that the timing of its installation follows the pattern of Cairncross's "value of 'machinery' retained for home use" series. This can be applied to non electric power to inquire how much of the 1907 plant still existed in 1912 and 1924 with an assumed 20 year life. For electric motors it is adequate to assume that half of the 1907 motors were installed before 1905. Many objections can easily be made against such calculations; but for what they are worth they suggest that just over half the new power plant installed, measured by horse power at the machine driven, was electrical. The calculation assumes that the length of life of plant was not affected by the introduction of the new electrical methods; this is theoretically indefensible, and allowance for it, were this possible, would reduce the proportion of electrical plant in the total of new plant installed.


3. For 1907-12 it is 56%; for 1907-24 it is 54%.

4. New power plant in this sense includes replacements.
The above calculation does suggest that electric power transmission methods by about 1907 had gained something like a 50% share of the power equipment business, and that this did not change much between 1907 and 1924. Thus it seems to have been the case that there was a sharp change in the relative attractiveness of electrical and mechanical power transmission systems between roughly 1902 and 1907.

The degree of electrification differs with industrial groups, and was low for some of the most important ones. In 1907 some 30% of motor power was in mines and quarries, where the percentage of motors powered electrically was only 5. Another 25% was in textiles, where only 4% of the motors were electrically powered. Iron and steel, the third largest power user among the major Census groups (20% of the total), had 12% of its motors powered electrically - that is roughly the national average. At the other end of the scale, marine engineering and shipbuilding had 55% and general and electrical engineering had 51% of their motive power applied electrically. But they accounted for only 2 and 5% respectively of the power used.

1. On the Census of Production classification.

2. The general basis of calculation is as for the aggregate in Table 54 except that the figures for motors driven by electricity purchased from outside have had to be allocated to industrial groups in a way which can slightly increase margins of error. See Appendix, where the full figures for all groups also appear.
This pattern persists. In 1912 34½% of total power in industry was in mines and quarries; only 19½% of that was electric. Textiles took another 27½% of industrial power with only 9½% of its motors powered electrically. Iron and steel accounted for another 22½% of total power, but had only 22½% of its motors driven by electricity. Again marine engineering and shipbuilding, and general and electrical engineering had 39½% and 72½% of motors driven by electricity with only 2 and 6½% respectively of total power. In 1924 the two industrial groups with a degree of electrification or power well below the national average were mines and quarries, and textiles. They accounted for 27½% and 13½% respectively of total power and had only 41½% and 26½% of their motors driven by electricity. Yet by then three groups had more than 90½% of their motors electrically powered, marine engineering and shipbuilding, general and electrical engineering, and cycles, motors and railway wagons. But only 12½% of the power equipment of industry was in these groups.

It is appropriate at this stage to inquire into the circumstances in which it was economically desirable to install electrical rather than mechanical power transmission. As the task performed, providing turning power, was similar in both cases one can concentrate on asking what resources, if any, were saved by adopting electricity.

1. For 1912 this refers to establishments employing more than 5 persons.
Turning power has a vast variety of applications, for example driving looms, lathes, coal cutters, steel rolling mills, cranes and riveting machines. In all these the relative advantage of electricity will differ. The information needed to go into details of multitudinous applications of electricity is very great, and all that is possible within the scope of this work is to make some general points.

Indeed, to do the work in details would require an inquiry into production methods which is impossible now, and would have been a very large task then, as necessary records of actual production methods were not generally kept, and studies of possible ones were not generally made, and certainly not disclosed. British manufacturers were secretive about the results of electric driving as they were about most matters where openness might reveal the cost of production. One example will suffice. In the early days of cotton mill electrification it was said that owners of electrified mills were very loth to make known the results fearing that their competitors would gain. The Electrical Review made the following comment in 1899:

"... There is no lack of information on the results of applying (electric) motors to machine driving, but unfortunately much of it is in a fugitive form and the ordinary engineer who sets out to give details of the advantages and disadvantages of electric motors, must have a special gift of research; and moreover, in dealing with the super abundance of materials that will eventually be discovered he must exercise much perspicacity and discrimination in order to arrive at correct results ... In spite of the accumulated experience that exists on the subject of machine driving it is notable how few are the conclusions one may draw from it".

As the leader went on to point out, published information was deficient. That given in papers to engineering societies was too vague; that given by manufacturers of electrical plant was often conflicting.

The first element of cost to be considered, and perhaps significantly the main one to be considered by British power users, was the cost of the power itself.

Among the various power uses there were some where the relative advantage (which might be negative) of electrical compared with mechanical methods of power transmission was greater. Firstly, there was the situation where power had to be applied in several scattered points in a works, in fairly small quantities, that is small in relation to the minimum efficient size of steam engines. If steam methods alone were used three alternatives were possible. One engine could be used with long lengths of shafting; but losses here could be very high, especially where the density of motors along the shafting was low. One boiler could be used connected to a number of engines by long steam pipes; but heat losses in the pipes could be high and small engines were thermally inefficient and had a high initial cost per h.p. The third method was to use a large number of engines and boilers; again they were thermally inefficient, capital costs per horse power were high and the cost of labour in fuelling boilers large. In these cases electricity offered advantages from as early as the nineties. Generation could be centralised, transmission losses were lower than with long lengths of shafting or
long steam pipes. Small electric motors were cheaper in the first cost and maintenance than small steam engines.

Even in the nineties electricity was not the only alternative to steam methods. There was the gas engine introduced in the 1870s. As early as the early eighties both Sir Frederick Bramwell and Fleeming Jenkin thought that it would fairly soon replace the steam engine.

But in the 19th century gas engines were very small. Not until 1898 was one of 220 h.p. built. Thus in the nineties it only competed with small isolated steam engines. But first cost was high and lower running costs were probably largely absorbed in higher maintenance costs.

The big gas engines of the years 1900–14 were not alternatives to electric driving but alternatives to steam engines to drive dynamos or shafts. In fact with their high speeds and poor low speed torque they were peculiarly suited to driving dynamos. Compressed air was also coming into use in the nineties. It was particularly suitable for operations like rivetting and drilling, but was a less simple method of conveying power than electricity. Compressed air tubes were generally not as convenient, efficient and cheap as electric cable. For rotating plant electricity was better.

Secondly as an extension to the first point electric power transmission was relatively more advantageous where connection to a

2. ibid.
central power supply was difficult. Travelling cranes are a good example. Before electric power they were virtually obliged to have their own boiler and steam engine. Also stationary hoists etc. were difficult to connect up to shafting because of frequent stopping and starting. Here hydraulic plant was frequently used. But it usually involved a separate power unit which was relatively expensive. Similarly variable speed tools and machinery could not be connected simply to shafting. Gears and clutches were expensive to maintain and much power could be lost in them.

Thirdly, in any single factory, electricity was relatively advantageous, not only where particular types of power application were needed but where several types of power were needed under the same roof. For electricity could cope with lifting and turning at constant and variable speeds. Other forms of power might be as useful for particular operations but had not the same range of usefulness. This range of usefulness meant that power generation could be centralised with consequent economies.

Fourthly, electric power was at a relative advantage where power was used intermittently. Where machines are being switched on and off during the working day it is extremely unlikely that all the machines would be switched on and off together. Thus the amount of prime moving and generating plant needed was less than the total horse power of motors powered. How much loss depended on proportion of the working day when machines were actually running, the loss function to be attached to not
being able to provide enough power for the machines, the overload characteristics of the prime moving and generating plant, and the correlation between the time of use of the various machines. This diversity varied with different industries. It was low in textiles where machinery was used continuously during the day only, and quite high in engineering where machines were used intermittently. H. McColl suggested that in engineering works it was usually found that generating plant equal to 50 - 60% of the aggregate maximum power of each machine was sufficient. This saving of power plant because of diversity applies to any centralised power generation system, mechanical as well as electrical. But diversity would rise as the number of machines connected rose, especially as machines of different types and with different patterns of use were connected. Thus diversity was generally greater with electricity. Also isolated steam engines driving single machines if used only intermittently were very wasteful of fuel, and by definition had zero diversity.

Compared with these types of power requirements electricity was at no relative advantage where power was required to drive machinery all grouped together and all requiring the same type of power. For

1. Prime moving and generating plant can be built to give, within limits, given overload capacities for varying lengths of time.

example, in a cotton mill all the machinery was grouped together. Shafting could be used to its best advantage as shafts did not need to be long, and the density of machines per foot of shafting was high. Nearly all machinery was used continuously. All the machinery required constant speed rotating power. Thus a central and efficient prime mover could be used.

Textile factories had conditions particularly suited to driving by central engine and shafting and it is thus not surprising that in such factories this system was best developed. Mill owners and managers had paid great attention to their power equipment. Their prime moving plant was more economical on the average than that of any other branch of industry. Steam engines were often specially designed for a particular mill. One of the important external economies of the cotton textile industry in S.E. Lancashire was the existence of well developed engineering firms skilled in providing for their needs.

"Probably in no other branch of industry, considered as a whole, will there be found such well designed and carefully built engines and such smooth running shafting as is the case in the cotton mills...

... until the adoption of electrical transmission of power in recent years (in other trades) ... the cotton mill was infinitely better equipped as regards its power installation than was the average engineering shop or shipyard".¹

This was despite the fact that it was in the same engineering shops and shipyards that engines and power equipment were built.

Matthew's statement was not likely to be contradicted; it seems to have been the generally held view.

It was primarily in the engineering trades that power was used intermittently in a scattered and/or varying way. There, there were chances of reducing power costs even in the nineties when electric driving was still in the development stage and the first cost of electric motors high. Perhaps the earliest industrial application of electricity was to cranes. As early as 1888 the engineering firm of Easton and Anderson adopted an electric travelling crane in their foundry. As they were also using a steam crane they were able to compare the two, and came to the conclusion that electricity was both cheaper and more satisfactory. No exact cost comparison had been made but it was said that fuel costs had been reduced to between a quarter and a third of the steam crane, that labour costs were also less because there was no need for a stoker to start work 1½ hours early to raise steam, and maintenance was also reduced.

Electricity also spread to other uses where transmission by existing methods was difficult. Shipbuilders were quick to use it. In the late nineties several yards, particularly on the Tyne, installed electric power. Significantly when Charles Herz was considering the application of electricity for industrial purposes on the Tyne in 1900–01 he was particularly anxious to use a system which would appeal to shipbuilders.


2. See Chapter 4, P. 137. Also Neptune Bank used marine engines partly to help in inducing shipbuilders to buy electric power from N.E.S. Co.
Shipbuilders had scattered and variable power uses. Merz argued that the adoption of electric driving by Tyne shipyards resulted in a 40% saving over the old steam driving.

In the coal mines power uses varied between those typical of textiles and those typical of engineering. Underground power requirements were scattered. Small units were needed for pumping, haulage and coal cutting. Pumping was often done by engines fed by steam from the surface. Haulage was effected either by engines again fed from the surface or by horses. Coal cutting machines were very little used but were very suitable for electric driving. On the surface there were often scattered power units for screening, repair shops, and also large economical engines for winding and ventilation. It was unlikely that electricity would be economical where large engines were already used. But for the various scattered applications it was comparatively better placed. For haulage it should have had something like the advantage of lower motive power costs over pit ponies that the electric tram had over the horse tram.

Where electricity could reduce actual power costs by reducing the cost of transmitting power over a given distance it would produce two principal types of saving. Fuel costs per unit of work applied to

the machinery could be less if an electric transmission system had a higher efficiency than a system of shafts and belts, or if an electric transmission system was installed instead of a set of small scattered engines, as small scattered engines had a relatively low thermal efficiency. Also the capital costs per unit of work applied to the machinery would be less. A higher transmission efficiency would reduce the capacity of prime moving equipment for a given power applied to machinery. Greater diversity would do the same. If the capital cost of an electrical system were less than the cost of a mechanical system the cost of a given capacity would fall. The same result would obtain if a central power unit replaced a series of scattered ones, as the latter had a relatively high first cost per h.p.

The reduction of fuel costs and the reduction of capital costs by reducing the prime mover capacity required was possible in some engineering factories, but was much more difficult in the largest of the factory trades, textiles, primarily because of the technique of production. The effect of the nature of the power requirements on the rate of adoption of electric driving in the textile industry was illustrated by contemporaries by the more rapid adoption of electricity by bleach and print works than by mills. F.S.A. Matthews argued that it was "not on account of any hostility on the part of the owners" that in 1907 there was little use of electric driving in Lancashire mills. This was clearly shown, he went on to argue, by the fact that electric transmission was adopted first in bleach works and print works, where "conditions are different from those obtaining in the spinning mills and weaving."

1. Used here to mean rate of doing work \( \frac{dw}{dt} \) where \( w \) = work and \( t \) = time.
sheds in so much as in those works a large number of auxiliary engines is required, and these being not so centrally situated as is the engine of a spinning mill, great economy in transmission could be shown by the adoption of the electric drive”.

There is not really any evidence on the relative capital costs of electric and mechanical power transmission equipments. But before the big fall in the price of electric motors 1901 - 05 electric motors were notorious for their high first costs. It was said in mitigation of this that electric motors had lower maintenance costs than shafting, but one cannot be sure that the comparison was not being made between new motors and somewhat elderly shafting. It seems almost certain that up to about 1901 the capital costs of electric transmission systems per unit of prime moving capacity were on the average above those of mechanical systems. By 1905 there was probably little difference between the two and electrical plant prices fell relatively, although at a slower rate than from 1901 - 05, from 1905 - 14.

One can say more about fuel costs, largely because this was what engineers were most concerned about. Even here the evidence is somewhat less than might be desired, primarily because of the lack of data about mechanical driving. Measurements of power and work are not too difficult with electrical methods as fairly good measuring instruments were soon devised. But there were no such good instruments for measuring the work done at various parts of a set of shafting and belting.

1. F.S.A. Matthews, op.cit.
The thermal efficiency of electric power transmission was fairly constant for most applications. But it varies with the time the system was at varying percentages of full load. At full load it would be about 80% but at half load it could easily be as low as 60%. In the early and middle nineties it was lower, perhaps 10% less.

The efficiency of mechanical transmission varied a great deal. W. Geipel summarised the available evidence for the British Association in 1898. In 1894 Professor Kennedy had estimated the loss in shafting at 22%. Crompton gave it at 32%. These were overall averages. Sir Thomas Richardson at his own works found losses of between 25% and 70% with a weighted average of 43%. Messrs. Furness, Westgarth and Company's engine works at Middlesbrough had an average loss of 50%. At the Bristol Waggon Works the loss had varied between 22 and 57%. In several factories in Cleveland, Ohio, C.H. Benjamin found the loss to vary between 50% and 80%.

1. This is a rough and ready statement. Efficiency would for example be affected by the length of cables used, or by the cross section of cables. Cables could be designed for varying losses in transmission.

2. Allowing 7½ loss in the dynamos, 2½ in the cables and 12½ in the motors.

3. Electric power and its application on the three phase system to the Bristol Waggon and Carriage Works. Paper to Section G, 12 September 1898.
On the average electricity was thus not a great fuel saver. In textiles it is unlikely that on the average electric transmission saved any fuel at all. In 1907 a paper was read to the Manchester section of the I.E.E. suggesting that for a mill using 100,000 spindles 3 phase electric power was slightly cheaper than mechanical power - 0.415d per KWh against 0.445. For smaller mills the author thought mechanical working was cheaper, and the comparative advantage of electricity increased with the size of the mill. But his figures were challenged in the discussion, and it seems likely that the margin of error was as large as the difference in cost. A 100,000 spindle mill was a big one. In 1911 the average mill had 60,000 spindles, but recently built ones were above the average.

In coal mining, an important example because of the size of the industry, the very low opportunity cost of coal meant that when fuel could be saved, the value of the saving was small.

In engineering where fuel might have been saved the saving could rarely have been sufficient in the nineties for it to be worth replacing mechanical drive with electrical drive. If we compare electric power with 70% efficiency with mechanical power with 50% efficiency the reduction in the coal bill would give a gross return on investment of perhaps between 2\$ and 8\%, with the average nearer 2\$ than 8, on the initial cost of the new equipment. In the years 1901 - 05 the cost of electric motor equipments halved and thus the rate of return would

1. E.R. Vol. 61, P 1006. 20 December 1907.
3. On P. 279.
3. This calculation is intended to show the orders of magnitude involved. Efficient reciprocating steam engines used about 3 lbs. per i.h.p. for average condition in the nineties. Coal in the factory bunkers cost between £0.5 - £1.0 per ton - usually nearer to £0.5. Assuming 90% engine efficiency, 50% efficiency in mechanical transmission and 70% in electrical transmission, the cost of fuel per brake horse power hour is

<table>
<thead>
<tr>
<th>Coal Cost per ton</th>
<th>Electrical</th>
<th>Mechanical</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>£1.0</td>
<td>0.512d</td>
<td>0.712d</td>
<td>0.204d</td>
</tr>
<tr>
<td>£0.5</td>
<td>0.259d</td>
<td>0.356</td>
<td>0.097</td>
</tr>
</tbody>
</table>

Factory motors ran between 1000 and 1500 hours per year on the average. Thus the saving p.a. per b.h.p. used was

<table>
<thead>
<tr>
<th>Hours used per year</th>
<th>Coal cost per ton</th>
</tr>
</thead>
<tbody>
<tr>
<td>£1.0</td>
<td>£0.5</td>
</tr>
<tr>
<td>1000</td>
<td>204d.</td>
</tr>
<tr>
<td>1500</td>
<td>306d.</td>
</tr>
</tbody>
</table>

The initial cost per b.h.p. of an electric motor transmission outfit depended on the size of motors used. Sizes below 10 h.p. were very costly and for general factory power firms would rarely go below this size, at least up to about 1905. In 1895 A.E.G. were selling 10 h.p. motors at about £8 per h.p. The price per h.p. declined up to about 50 h.p. when it reached £4 and thereafter remained constant. This is for d.c. motors; a.c. motors were still in their infancy and although the 10 h.p. size was again about £8 they did not fall below £7 as the size rose. Let us take 10 h.p.; bigger motors were used, but frequently to drive small pieces of shafting. Dynamos being bigger, wore cheaper per h.p., say an electric power transmission system, assuming the same steam engine could be used, would cost about £16 per h.p. in 1895. This is a minimum as the cost of erection has not been included.

Thus we can calculate the gross return, before depreciation, p.a. on replacement of shafting by electric motors.

<table>
<thead>
<tr>
<th>Hours used per year</th>
<th>Coal cost per ton</th>
</tr>
</thead>
<tbody>
<tr>
<td>£1.0</td>
<td>£0.5</td>
</tr>
<tr>
<td>1000</td>
<td>5.3</td>
</tr>
<tr>
<td>8.0</td>
<td>3.8</td>
</tr>
</tbody>
</table>
be doubled. As depreciation on this type of plant was about 5%, even then it is a barely adequate return on the average.

A comparison of a centralised electric drive with a number of scattered steam engines brings out the same point. In 1898 W. Mavor of Mavor and Coulson, a Glasgow firm, one of the pioneers of electric motor driving, sent a questionnaire to manufacturers in an attempt to get better information. The replies he got were admittedly incomplete but sufficiently good for him to be able to divide firms into two groups. One was mills and similar establishments where one or two efficient engines were used. The other was where power was derived from a number of small steam engines. On the average the first group used 3.1 lbs. of coal per i.h.p. hour, the second 5.3 lbs. In the former case no fuel saving could be expected from electrification. Electrification could improve the second group until the same amount of fuel was used as in the first. The value of this fuel saving was slightly less than that in the earlier examples of mechanical and electrical driving and thus the return on investment less.

1. Both averages are weighted by the amount of power used.

2. If a central engine was used with electric power transmission using 3.1 lbs. coal per i.h.p. hour then assuming 90% engine efficiency and 70% efficiency in transmission, 4.9 lbs. coal would be used per b.h.p. hour applied. Scattered engines using 5.3 lbs. per i.h.p. hour applied direct, assuming 90% engine efficiency, would use 5.9 lbs. per b.h.p. hour employed.

Costs per b.h.p. hour (d.)

<table>
<thead>
<tr>
<th>Coal cost per ton.</th>
<th>Electrical</th>
<th>Scattered steam engines</th>
<th>Difference.</th>
</tr>
</thead>
<tbody>
<tr>
<td>£1.</td>
<td>.526</td>
<td>.631</td>
<td>.105</td>
</tr>
<tr>
<td>£0.5</td>
<td>.263</td>
<td>.315</td>
<td>.052</td>
</tr>
</tbody>
</table>
Reference 2 continued.

Fuel saving per year (d.) of electrical method per h.p.

<table>
<thead>
<tr>
<th>Hours per year</th>
<th>£1</th>
<th>20.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>105</td>
<td>52</td>
</tr>
<tr>
<td>1500</td>
<td>158</td>
<td>78</td>
</tr>
</tbody>
</table>

Thus on Knor's figures the electrical savings come out at a smaller figure than in the previous notes. The argument used there applies a fortiori.
Thus up to the big fall in motor prices of 1901-05 there was little reason on the average to convert to electric driving to save fuel. But the dispersion of fuel costs of steam plant was very large. Mavor found instances of extremely wasteful engines. Some he found were using 55-180 lbs. of steam per i.h.p. hour, even in factories where other engines were working at the very economical rate of 14 lbs. Many of these engines were very old, often 20 years old. They could, he thought, be profitably replaced by electricity. But it is likely that it would have been profitable to replace them by up to date steam engines. There is some truth for the nineties in the contention of G.T. Duncan provoked by a paper on electrical power transmission in 1895:

"In papers of this sort comparisons have only been made with steam engines, which in most cases are apparently of ancient design and construction and ill adapted to the work in which they were engaged during the tests, thus showing an abnormal and unreliable coal consumption ... while on the other hand the electric plant has been of modern construction ..."*

Also in the nineties it would be worth replacing mechanical with electrical plant to save fuel if the engines were very small, or the shafting was very long or transmission very difficult.

In the case of equipping new factories, electric driving was more likely to be adopted. But for a large number of applications for much of the nineties the fuel saving was slight, often not enough to offset the higher capital costs of an electrical system. Throughout the

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nineties the capital costs of an electrical system fell slowly relative to the capital costs of mechanical systems, thus changing the position from that of the middle nineties when adoption of electric rather than mechanical driving very rarely reduced power costs, to that of the late nineties when it only occasionally reduced power costs.

After 1905 the position was substantially changed. It was much more likely to be worth replacing existing mechanical plant, and thus a fortiori installing electrical plant in new factories. The deterrent of high capital costs was generally removed. In the typical engineering shop the balance seems to have been firmly tipped in favour of electric driving. But in textile mills it was still an open question. Also the reduction of motor prices brought power within the reach of small workshops who had hitherto used no power at all, and small factories which had used very little. Clapham notes the much more rapid rise in the number of factories than workshops. The distinction is made according to whether power was used or not. The number of the former, using power, rose by 26.9\% from 1901 - 1913, and the latter, not using power, by 13.7\%. From 1895 to 1913 the former had risen 22\% and the latter 32\%.

By the nineties the reciprocating steam engine was near the limits of its potentialities. From about 1907 - 10 onwards two new economical prime movers came to be used in factories, the steam turbine and the internal combustion engine. However they stimulated the use of

electricity, for they operated best at a high speed and for use with mechanical transmission would have needed gearing. Electric transmission automatically met this need, and met it much better where large powers were involved. It reduced the amount of electricity which might have been bought from public utilities, but to confuse buying electricity with using it is a mistake of the first order.

To consider power costs alone is quite inadequate. It can indeed be argued that they were of minor importance. Other resources could be saved because the use of electrical methods could increase output without increasing inputs, or more generally because it did not increase the cost of all inputs proportionately as much as the value of output rose.

The simplest way in which this could happen was by increasing the physical output from existing machines, or the value of output. This could occur because of more accurate control of machinery. One such application was the use of electricity on the Ward-Leonard principle to control very large motors. In this way the stopping, starting and speed of large machinery could be much more accurately

1. The principle behind the diesel electric locomotive is that electricity is used to provide the transmission instead of gears and clutches, as in a diesel bus or lorry. Electricity can much better deal with large powers than gears and clutches. Another illustration comes from ships where turbo-electric power was experimented with rather than geared turbines.
controlled than if they were driven directly by steam engines.

Hard-Leonard sets were used to drive steel mills and other similar pieces of very heavy machinery. Smaller but still fairly large machine tools could be more accurately controlled by the current fed to the motor, if electric motors rather than steam or gas engines were used. Thus spoiling of products was reduced and the value of output raised. The electric motor had a large overload capacity and thus could cope much better than steam or gas engines with the heavy and sudden strains imposed by large machine tools. For this reason also the machines could be speeded up and/or the rate of spoiling reduced. It was significant that where electric motors were used in the early days of the late nineties it was where heavy intermittent strains were thrown on the motors. The Electrician commented in 1898 that nowhere had electric driving been so extensively and successfully practised as in the shipbuilding yards of the North East Coast.

Probably, it continued, no class of machine tools threw heavier and more trying strains upon the driving plant than the large rolls, plate bonding machines and wall planers used in such works. This was largely because of the contribution of electricity to raising output. At Sir Thomas Richardson and Sons' engine works at West Hartlepool output

1. A. Hard-Leonard set is a combination of prime mover, generator and electric motor. The power exerted by the electric motor is governed by regulating the minute small currents used in the field coils of the generator. Thus delicate control of large power is possible.

rose by 20% as a result of the introduction of 3 phase electric driving.

Merz argued that the output of Tyne shipbuilders had risen because of the adoption of electric power.

3 phase electric motors maintain an almost constant speed under varying loads. Their speed variation was much less than that of shafting and belting under similar conditions. J.F. Crowley made a study of this in the case of textile machinery. His results are in Table 55 below.

Table 55.

Speed variations in textile machinery.

<table>
<thead>
<tr>
<th>Type of machine</th>
<th>Maximum speed range as % of mean speed</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Spinning</strong></td>
<td></td>
</tr>
<tr>
<td>Dale Countershaft</td>
<td></td>
</tr>
<tr>
<td>mechanical drive</td>
<td>25</td>
</tr>
<tr>
<td>individual electric drive d.c.</td>
<td>17</td>
</tr>
<tr>
<td>individual electric drive a.c.</td>
<td>6</td>
</tr>
<tr>
<td>Ring doubling frame</td>
<td></td>
</tr>
<tr>
<td>mechanical drive</td>
<td>6</td>
</tr>
<tr>
<td>after conversion to individual electric drive</td>
<td>0.5</td>
</tr>
<tr>
<td><strong>Weaving</strong></td>
<td></td>
</tr>
<tr>
<td>Loom Shaft line (near belt drive)</td>
<td>9</td>
</tr>
<tr>
<td>(middle of shaft)</td>
<td>12</td>
</tr>
<tr>
<td>(end of shaft)</td>
<td>16.5</td>
</tr>
<tr>
<td>(group electric drive)</td>
<td>6</td>
</tr>
<tr>
<td>Loom (individual electric drive)</td>
<td>2</td>
</tr>
</tbody>
</table>


The reduction in speed variation, it is shown, depends not only on electrification but on the degree of subdivision of the electric drive. A more even speed of driving reduced the number of times the thread broke, and thus increased the rate of output of the machine. In 1905 it was said that output could be increased by up to 4% in weaving and up to 8% in spinning by adopting electric driving. In 1904 E.J. Williams reported on a study of the use of electricity in hosiery manufacturing. He argued that the loss in cloth due to the poor speed regulation of the steam engines usually driving power frames was very considerable. Electric driving would eliminate this, which he thought was of the order of 25 - 30%.

If variable speed power was required electrical driving also offered the advantage that the speed of the machine could be divorced from the speed of other machines in a way which was more difficult with belting and shafting. Hence machine operators were no longer restricted by the speed of the shafting, and output could rise.

In all these cases capital and labour would be saved per unit of output. Sometimes raw materials would also be saved. If the ratio of capital to labour remained constant the proportionate savings in labour and capital could be the same. But ease of operation of machines might lead to a fall in this ratio, thus saving relatively more labour.


There are also cases where output could be increased by the application of electric power where power had not hitherto been applied because of high cost. This was the case in small light industries where the establishment was very small, and also in coal mining. Both were heavily labour intensive and thus the main resource to be saved was labour. Coal mining is particularly important in this context because of its importance in the economy and as a power user.

In coal mining one might have expected that output and labour productivity might have been increased by the use of electricity underground, principally for coal cutting, pumping and haulage. It would seem to have been an improvement on what power was used underground. Haulage and pumping were sometimes effected by steam engines fed with steam by long pipes from the surface. Mechanical coal cutters were used in the nineties driven by compressed air. Compressed air transmission underground was difficult and often not satisfactory. The electric coal cutter became more popular. In 1912, 59.9% of the coal mined by coal cutters was mined by electrically driven ones.

But coal cutters were very rare in British mines right up to 1912. In that year only 7.7% of the coal raised was mined by coal cutters. This is incidentally one of the reasons for the slow adoption of electricity in the mines. Had half the coal output of 1912 been mined by cutter half as much electric power again would have been used. Also

2. E.R. Vol. 73, P 597. 10 October 1913.
coal cutters were expected by some to provide an entrance for electric power into the mines, leading eventually to its wider use. In the event, in 1912, coal cutters (included under portable machinery in Table 56) were relatively unimportant.

Table 56.

<table>
<thead>
<tr>
<th></th>
<th>000 h.p.</th>
<th>% of total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Surface</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Winding</td>
<td>23.9</td>
<td>4.7</td>
</tr>
<tr>
<td>Ventilation</td>
<td>30.9</td>
<td>6.0</td>
</tr>
<tr>
<td>Haulage</td>
<td>73.8</td>
<td>4.6</td>
</tr>
<tr>
<td>Coal Washing</td>
<td>43.6</td>
<td>8.5</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>72.0</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>510.8</td>
<td></td>
</tr>
<tr>
<td><strong>Underground</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Haulage</td>
<td>150.0</td>
<td>25.4</td>
</tr>
<tr>
<td>Pumping</td>
<td>144.3</td>
<td>23.2</td>
</tr>
<tr>
<td>Portable machinery</td>
<td>31.0</td>
<td>6.1</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>11.3</td>
<td></td>
</tr>
</tbody>
</table>

Source: E.R. Vol. 73, P 864. 14 November 1913.

The slow adoption of the coal cutter has been investigated by A.J. Taylor. He argues that although coal cutters existed before 1830, experiments with early cutters were discouraging. At first compressed air was the favoured method of driving them but transmission 1.

1. For example by Charles Lanz. See his Report to R.S.M. Co. on supply to R.S.M. Co.'s Northern areas. 21 December 1903. Carlisle House Records.

was difficult. Electricity was disliked by colliery managers and also by mine inspectors at least until the 1904 Home Office Department Committee investigated electricity in the mines. Also it must be added that up to this period electrical engineers had done little to develop motors for coal cutters. As has been pointed out their general attitude to electric power was passive. Particularly relevant was their failure to develop 3 phase power, for the 3 phase motor had no commutator and thus did not spark. As late as the end of 1903 there were only 12 British 3 phase coal cutters. Taylor argues that there is not enough evidence for one to say that the coal cutter certainly reduced costs or increased output (either in quantity or quality) sufficiently to be worth adopting it. The main reason for its adoption he argues, is that it could make the mining of very thin seams possible. He quotes with approval the statement of the official spokesman of the mine owners before the Samuel Commission in 1925 - "Generally speaking the saving in labour charges at the face is absorbed by the capital charges and the running costs of the machine."

This argument that increases in labour productivity were often not sufficient to make the adoption of power worth while is explained by Taylor by the abundance of labour supplies. This argument can work in two ways. One is that in the long run, that is over a period longer

than the wage cycle, the elasticity of supply of labour was so high that wage costs per ton mined did not rise, and thus the rise in the demand for coal led to little mechanisation. The other is that the working of the wages cycle was an additional dampening factor.

The following chart presents an index of wage costs. This is simply an index of miners' wages divided by an index of tons mined per man employed. Thus it relates to all the operations of the coal mine and not simply to underground ones. The index shows an upward trend but wage costs do not rise sharply until after 1906. Looking at the picture up to then there would have been no reason for mine owners and managers to suspect that wage costs were turning sharply against them despite the falling productivity of labour.

The stimulus of what rise in wages there was before 1907 was lessened by the way in which the wage cycle worked, and by its timing. On the upswing wages rose although not sharply until the later stages. Physical productivity fell as wages rose. In the downswing the reverse occurred; wages fell while productivity rose. Employment also rose in the downswing, and thus there would have been little incentive to mechanise. In the upswing, however, especially in its later stages, there would be quite a powerful stimulus to do so. Here labour supply certainly does not appear to have been elastic.

It is a doubtful procedure to try and establish the elasticity of supply of labour from time series information alone. But the analysis which is possible, and not perhaps too implausible, suggests that the elasticity of supply of labour, although high in the first year of an
Wage index/production per man employed (tons)
The upswing soon became low.

Simply on these grounds one would expect coal cutters to produce sufficiently large increases in labour productivity to justify themselves in the later stages of the upswing of the boom. The boom which broke in 1900 came too early, before there were good enough and cheap enough electric motors. From 1900 - 05 falling wages and profits would act as a disincentive. From 1906 onwards cyclical and secular influences both push wage costs upwards. And as far as one can tell the number of coal cutters responds to this. In 1902 H.M. Inspector of Mines reported that there were 14,5 electric coal cutters. In 1912 there were probably 10,000 - 15,000. And they were rapidly increasing in number; in 1912 27.7% of the coal raised was mined by cutter, in 1913 8.5%.

1. I assumed a 2 year lag between wage rises and an increase in the supply of labour (measured simply in numbers employed). For the upswings of 1895 - 1900, 1905 - 07 and 1910 - 11, the following figures of arc elasticity of supply emerge:

<table>
<thead>
<tr>
<th>Year</th>
<th>Elasticity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1895-6</td>
<td>1.53</td>
</tr>
<tr>
<td>1896-7</td>
<td>1.49</td>
</tr>
<tr>
<td>1897-8</td>
<td>1.06</td>
</tr>
<tr>
<td>1898-9</td>
<td>0.82</td>
</tr>
<tr>
<td>1899-1900</td>
<td>0.15</td>
</tr>
<tr>
<td>1905-06</td>
<td>1.21</td>
</tr>
<tr>
<td>1906-07</td>
<td>0.17</td>
</tr>
<tr>
<td>1910-11</td>
<td>1.12</td>
</tr>
</tbody>
</table>

A one year lag gives the same pattern, with, as one would expect, lower elasticities.

If labour were measured in man hours the figures would be lower as absenteeism increased as wages rose.


3. Taylor, op.cit.
This situation where the adoption of electricity was labour saving and capital using has been dealt with at some length, partly because of the size of the coal industry and partly because it was the general situation which would apply when electricity made it economical to use power, when it had not otherwise been so. But in the case of many factory trades, where electric power might be used rather than mechanical power, there would often be considerable capital saving as well.

The adoption of electricity could however produce savings of inputs in other ways. Electric cables were lighter than shafting. Also they took up less space and thus new factories could be of lighter construction and need not be so high for a given purpose. New and expanding firms could buy a cheaper building for the same purpose.

Unfortunately we have little data on the difference of building costs between mechanical and electric transmission. That the matter is rarely mentioned may mean that it was small.

Much more important than the weight of electric cables was their greater flexibility. This could reduce the effect of the power system on the layout of the factory. When shafting was used machinery was usually

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1. One case may be worth quoting. In 1894 Messrs. Campbell built a new clothing factory at Leeds. Electric driving was installed from the outset, necessitating a lighter construction of building than usual, which was said to save £2000. "Before building operations, specifications were asked for steam plant with ordinary shafting and belting, as well as for the electrical scheme. The first cost (of the power equipment) was about equal but electricity offered distinct advantages in that a cheaper kind of building was only necessary".

E.R. Vol. 35, P 405. 5 October 1894.

It is a significant comment on the value of the information that we do not know the size of the factory.
grouped closely around it. Electric cables were physically more flexible and thus even if the power cost, capital and running, of electric transmission was as high as that of mechanical transmission when the machinery was closely grouped together, it would be lower when machinery was more dispersed. Electric motors could be put in any position. Thus more weight could be attached to other factors like simplicity and speed of handling, simpler access to machinery. Even if machinery worked at the same speed, and thus the rate of output remained constant, the reduction of time between operations would reduce labour costs, and also capital costs as the value of work in progress fell. Even the existence of shafting apart from its effect on the arrangement of machinery could impede handling. For example, a travelling crane would be slowed down. Lighting was more difficult with shafting, and thus would cost more, or operations would be slowed down because of poor visibility.

The extent of the cost saving varied with the degree of reorganization which was made in the arrangement of the shop. It could be considerable. For example, in an American rolling mill the adoption of electric driving had reduced the number of men required from 6000 to 4000. Lars argued that one of the very important advantages of electric power was that it permitted a completely different layout of the works.

The saving did not end with making better organization possible, for electric driving could stimulate further thought on better planning.

1. Select Committee of the House of Lords, Qs-12-and-15, on the Administrative County of London & District Electric Power Bill. Qs. 11 and 15.
and arrangement of work. It could do this in two ways. Firstly, by considerably weakening the ties between the layout and the power system it could stimulate much more consideration of factory layout. Once a constraint on what can, reasonably cheaply, be done is removed further innovations may easily follow. The potentialities for this were great. The majority of British workshops and factories at the time were very ill planned. Machinery was huddled together in small, dark and dirty buildings, the latter were often badly laid out and difficult to manage. There is much justice in the comment that it was the state of building and layout rather than the age of the machine tools used that contributed to the often high costs of British industry. One must not overrate the contribution of electric driving to better lay-out. There are a number of other reasons for planning improvements and the influence of electric driving in this respect was only permissive. But one still may suppose it was considerable.

The other effect that the introduction of electricity had on management was that measurement became much simpler. At the turn of the century very few measurements were taken of the energy input in manufacturing. There were neither many measurements of physical input nor of the cost of this input. Engineers who pioneered electric driving soon discovered a great deal of antiquated machinery, machinery which probably would have been scrapped if rational calculations had been made. Such plant was not to be found simply in the backward industries;

often manufacturers of power plant were content to use obsolete equipment. One of the important things which intending sellers of electrical driving plant could do was to draw manufacturers' attention to their power plant and persuade them to investigate the costs of the equipment they could use, and that which they were using. Once encouraged careful scrutiny of costs could be applied to other inputs as well as power.

In this context it is worth paying attention to the views expressed by W.J. Aldrich to the Milwaukee meeting of the American Society of Mechanical Engineers in 1901, when he was discussing the use of electricity in manufacturing. He argued that the advantage of electricity was not in the small saving in the fuel bill, but the very large increase in output which was made possible by using it. Output per man, output per square foot of factory space, output per machine all rose substantially. It was much easier, he went on, to increase output in this way than through new buildings, men and machines. Labour conditions were improved; the men were enabled to work faster, not being tied to the speed of the belting. The shops could be better laid out when no overhead shafting was needed. All parts of the machinery would be accessible and their maintenance costs reduced. The various buildings need no longer be grouped round the power house, and thus could be better arranged for efficient working.

Adoption of electricity did not always facilitate production. For example, in coal mining it was sometimes said to be disadvantageous.

because it increased danger. Colliery managers were quick to point
to the possibility of sparking at the commutator of a.c. motors and to
stress the danger of this in fiery mines. They were also afraid of the
consequences of underground cable faults. These difficulties were much
exaggerated as the risk was only very slight with careful engineering.
But they existed. It was not only the use of electricity underground
that they mistrusted; they feared that winding and ventilating machinery
if driven by electricity would be more liable to break down than if driven
by steam engines. The consequences of such breakdowns could be very
serious. It must be remembered that up to about 1900 electrical
machinery was not entirely reliable. To see this one only has to read
accounts of the working of early power stations.

It is also said that in textiles a disadvantage of adopting
electricity was that a considerable amount of steam was required for
process work. This, however, was only a disadvantage of electric
driving on electricity bought outside. If electricity was generated by
the mills, and there was usually little reason to suppose this was more
expensive, there would be the same supplies of steam as if mechanical
driving were used.

The earlier argument that electric driving would save more
resources if allied to reorganisation of the works and/or better planning
of work can be extended. Innovations may be complementary; if two
innovations are adopted jointly they may save more resources than the sum

1. See R.H. Parsons, *op.cit.*
of resources saved if both were adopted independently. Coal mining provides a good example. In the years 1900 - 1914 there can be little doubt that in some mines resources could have been saved by a better layout of the mine, for example by bigger, better and more level main galleries and by easier working conditions at the coal face. Electric coal cutting and electric haulage would also have saved resources in some cases. But one would expect the joint saving to be greater than the sum of the two applied separately. This is because quicker coal cutting and quicker haulage exploit more fully the straighter, more level galleries and easier coal faces.

In engineering the same applies to more accurate machine tools which could reduce the cost of engineering products by substituting lighter, more exactly made parts for the robust, heavy ones usually used. British engineering products were relatively heavy compared with those of say, America. This was partly a substitution of weight for good design and careful machining. For example, in the eighties electrical machinery was often flimsy. Mechanical engineers took up its manufacture in the nineties, and considerably improved its robustness. But they did this by building very much heavier machinery rather than by very careful attention to its design.

In the Tyneside shipyards electricity was adopted at a time when the general technique of production was changing. In the late nineties Tyne shipyards were changing over to a system of working in covered sheds rather than in open. Also more power was being used especially for

riveting and drilling, employing compressed air as well as electricity.

Factory buildings are another example. If they were made more regular and higher so that machinery could be well laid out and electric travelling cranes used, electric driving would be able to make a greater contribution to cost saving than if it were merely installed in the same buildings. But more regular buildings would have reduced other costs even without electric driving.

All these innovations which involved changes in capital equipment, were more likely to be adopted in an economy where capital was rapidly growing. The British economy was growing only slowly at the time. W. Hoffmann has calculated that from 1875 to 1913 industrial output was growing at a rate of only 1.7% p.a. They were also more likely to be adopted where the rate of scrapping was high. The more frequently machinery of all types was replaced the more feasible were extensive changes in layout. Where plant was built to last a long time, as was most British factory plant, patching up an existing layout by changing isolated machines independently was more likely.

Contemporaries argued that electricity was too slowly adopted in England, and that two important explanations were lack of technical knowledge, and, more generally, conservatism. It is not difficult to find examples of both. The coal industry is perhaps the happiest hunting ground. "Electricity," wrote Clapham, "as might have been expected made

only sluggish progress in the mines". He argued this on the grounds that coal mining seemed slow to develop most new techniques. Colliery managers were ex-pitmen, not engineers, and there is much justice in the contemporary complaints that they had only enough training to think of objections to innovations which came to their notice. In the case of electricity, possible danger was quickly spotted, and so generally used as an argument against electrification that in 1904 a Home Office Departmental Committee was appointed to consider the matter. But coal is not typical, and is to be contrasted with engineering. For example, N.E.S. Co. found that while Tyneside engineers naturally came to them to discuss power matters, the coal owners in Durham had to be offered all sorts of inducements even to open negotiations.

Conservatism is a very wide term, not sufficiently well defined to be useful as an explanation. But the discussion of the relation between the adoption of electricity, increases in output, and resource saving enables one to be more precise. The more ready business men were to consider large changes in the techniques of production the greater the possible cost saving. Their readiness to look at the advantages of electricity was allied to their readiness to take advantage of other improvements, associated with electricity only in so far as they were complementary innovations. British business men tended to think of the advantages of electrification as being largely those of saving the cost

2. ibid. PP 162 - 6 for examples.
3. N.E.S. Co. Historical Records.
of power. This reluctance to think of and undertake radical changes can be described as a type of conservatism, but it is clearly not the same as the reluctance to undertake any changes. But any tendency to concentrate attention on power, costs would lead to less electrification than could be rationally justified.

The matter cannot be exhaustively considered here. What would be needed is studies of individual industries covering all potential innovations during the period, and their relation to electric power. It would be a very large undertaking indeed.

This is closely connected to the allegations of lack of technical knowledge. When people began to worry about this in the 1870s, there was a general lack of technical knowledge. But by 1900 this had been partially remedied. There had been a big increase in the number of engineers trained to a modest level in particular branches of the subject, for example electrical engineers trained at evening classes. But few people at the highest level of industry had engineering training. Such men would, no doubt, pick up a lot of engineering knowledge of particular matters with which they were closely connected, but would not have any training to be able to consider a wide range of engineering matters. It was wide and varied knowledge which would equip a man for consideration of the potential profitability of a wide range of innovations to be adopted jointly. Specialist advice could only be offered about adoption of single innovations.

There was an increasing number of complaints during the decade before 1914 that the prime manpower deficiency in British engineering
particularly was the lack of good "commercial engineers", that is of men who combined engineering skill with skill in the market place. There seems little doubt that there was such a shortage.

Electric driving, it has been argued, saved inputs per unit of output primarily by enabling greater output from a similar set of productive resources. Here one must look at how eager British business men were to increase output. This depends on the elasticity of demand, and the expansion of markets, as well as on lack of willingness to find and develop new markets. The latter can be called conservatism, but not the former.

There are not enough studies of the elasticity of demand for the products of British industry for one to be able to say much about the matter. In the case of the steel industry, D.L. Burn has argued that demand was often inelastic because firms enjoyed a considerable element of local monopoly. But about the slow growth of demand in general there can be no doubt. Thus compared with a fast growing economy there would be much less incentive for British business men to electrify.

Another way in which determination to increase output in the fairly short run - over a year or so - because the expected value of future profits was high or thought to be high, could lead to electric driving was because it was much simpler to install new electric motors, than to extend a system of shafting and belting. Thus small extensions to capacity were much cheaper with electric driving even if large extensions, where a new set of shafting could be installed, would have

been more cheaply made with a mechanical power transmission system. In other words electricity could make indivisibilities divisible.

\[ \text{Average Cost} \]

\[ \text{Output} \]

LAC is drawn as an envelope assuming constant costs and no indivisibilities beyond a low level of output.

\[ \text{SAC}_m \] = short run average costs of mechanical drive.

\[ \text{LAC}_e \] = long run average costs of electrical drive.

Conservatism in the sense of reluctance to consider radical changes in the process of production could be overcome by a vigorous sales policy on the part of the manufacturers of plant incorporating innovations. It was asserted by those connected with N.E.S. Co. who
were very successful in persuading manufacturers to adopt electric power, that a vigorous sales policy was essential, but if pursued with determination would be successful. A vigorous sales policy meant cheap electricity plus every attempt at persuasion. As Charles Mers told a Select Committee of the Lords

"It is therefore essential in this country that there should be current available at an exceptionally low price? Yes, and the body who wants to supply the power must adopt a good deal of energy and push, and put every possible convenience before the manufacturer, or he will not give up his old plant." 1 'The manufacturers in this country had in the majority of cases established his works before electricity was a commercial question. The result is that he has now got his plant, and is very loth to spend money on buying new plant .... Every possible inducement must, therefore, be offered to get that manufacturer, by offering to make all sorts of arrangements with him to simplify the operation of modifying his works. It may be that motors are sold on an instalment scheme, it may be that they are hired out .... Every man has some special whim or idea as to the way in which it should be done.... "On Tyneside at the present time the power company have in manufacturers' works over £100,000 worth of apparatus either hired out or exchanged for old plant or dealt with in some way; and it is largely due to the fact that the power company, from the very start, determined to get all the business that they have got it". 2

Among supply companies N.E.S. Co. was the one that stood out as one with a vigorous sales policy; it was also the most successful. This suggests that there were obstacles of the type mentioned to overcome.

The same type of argument applied to electrical plant manufacturers who wished to sell plant to power users who would generate their own current. It was argued, for example, that A.E.G. had been able to sell

2. ibid., p. 97
a great deal of electrical plant in the South Wales Coalfield because they
had sent competent engineers to possible consumers to persuade them of
the advantages of electrification.

It was suggested earlier in this chapter that manufacturers of
electrical plant, by their passivity, delayed the introduction of electric
power in the late 1890s. This happened to coincide with a major boom in
factory equipment. This is clearly shown in Cairncross's table of gross
investment in machinery, which shows a considerable upswing in the middle
nineties.

Table 57.

<table>
<thead>
<tr>
<th>Value of &quot;Machinery&quot; retained for home use</th>
</tr>
</thead>
<tbody>
<tr>
<td>£m</td>
</tr>
<tr>
<td>1884-93</td>
</tr>
<tr>
<td>1889-93</td>
</tr>
<tr>
<td>1894-93</td>
</tr>
<tr>
<td>1899-1903</td>
</tr>
<tr>
<td>1904-05</td>
</tr>
<tr>
<td>1909-1913</td>
</tr>
</tbody>
</table>


By 1904 when the price fall in electrical equipments was swinging
the balance towards substantial electrification a large amount of
machinery must have been relatively new. Once new machinery was installed
it would delay electrification because the latter would be accompanied
The timing of cyclical fluctuations also affected electrification in the important textile industry. The last big textile investment boom was 1905-08. It has been argued above that the advantages of electrification were less in textiles than in other industries. They were probably very slight before about 1910. We have no precise information on this. In 1910 the Electrical Review commented that owners of electrified mills were very loth to make known the results, fearing that their competitors would gain. But it went on to conclude that the results were not likely to have been unfavourable or a great deal of grumbling would have been heard.
In this chapter we shall discuss the beginnings and early growth of the manufacture of electrical machinery. Electrical machinery is here taken to cover generators, a.c. transformers, converters, motors, switchgear and arc lamps. This group of products by no means covers all the equipment used in connection with the generation and use of electricity. Power stations use boilers and steam engines as well as generators and transformers. Electric tramways and railways are rolling stock of which only the motor equipments are electrical. Nor does this group cover all the electrical equipment used for electric lighting, electric traction and electric power. Electric incandescent lamps, electric cables, storage batteries and electrical instruments are generally excluded.

Electrical machinery has been grouped together largely because all the products in this group required similar techniques of production. Similar knowledge was required for initial designs, similar labour and machinery was used in actual manufacture. Generally speaking these inputs

1. Rotary converters, motor generators, motor transformers and motor converters. They were used for converting a.c. into d.c. or changing the voltage of d.c. They have all been superseded.
could be easily shifted from one product within the group to another. Skilled labour and general purpose machinery was largely used. Machinery was built in large shops not usually specially adapted for any particular product. There are some differences between products and these differences are sometimes important. Except for small motors and tramway motors nearly all electrical machinery was built to order. This was particularly true in Britain.

Another reason for grouping electrical machinery together was that it was made by a fairly distinct group of firms. Most of our information about electrical machinery manufacture is based on rather patchy biographical information about individual firms.

Special attention has been paid to the manufacture of machinery for several reasons. Firstly, innovations in machinery were often crucial, for example the Brush high voltage dynamo, the American traction motor, or three phase a.c. machinery. Secondly machinery is in a central position touching the introduction and extension of electricity for lighting, traction and power. Even when innovations take place outside this sector, for example the introduction of the steam turbine, which is not an electrical machine at all, modifications have to be made in electrical machinery. Thirdly innovation in the machinery group was more continuous than in other sectors. In incandescent lamps there were two periods of innovation, firstly the invention of the lamp itself in the years 1878 - 1883, and secondly the invention of a metal filament lamp in the years 1897 - 1912. In cables there was the development of new mains in the years

1. B.A. Bright Junr. op.cit.
1883 - 1893 including the first use of paper as a dielectric. After that, modifications were individually small. Fourthly the introduction of electricity for lighting, traction and power produced a distinct new branch of manufacturing. Cable makers manufactured telegraphic cables before electric lighting became feasible. Engine and boiler builders adapted their product for use in conjunction with electrical machinery, but they remained primarily engine builders. Fifthly more has been written elsewhere on cables and electric incandescent bulbs.

The output of electrical machinery fluctuated. Unfortunately it is not possible to construct any time series of output before 1896. From 1896 such a time series has been constructed and is in Table 23.

The general shape of fluctuations is, however, clear. From 1879 to 1882 both the value and volume of output were rising. In 1883 both slumped and from then until 1887 while the volume of output seems to have risen, the value remained generally stationary. From 1887 - 91 another boom came with something like a tripling of the value of output over these years. From 1891 - 95 comes another recession. The value of output however seems to have gone on rising slowly. Prices fell steeply and the volume of output must have quite substantially risen. Beginning in 1896 came another upswing, this time a very big one, leading to a major boom which lasted until 1903. After 1903 the value of output began to decline, although only slowly at first. The volume of output continued to rise, although


3. A.A. Bright Junr. op.cit.
more slowly and only intermittently. Prices, which began to fall in 1901 because of German competition continued to fall rapidly. This period lasted until 1910. In 1911 the value of output began to rise, and continued to do so until 1914. The boom persisted during the 1914 - 18 war but partly because of special wartime conditions. Thus although there were strong upswings in output, there were, except for 1883 no strong downswings.

In this section we shall be concerned with the first boom and slump, i.e. from 1878 - 1887. In this period the main products were arc lamps and arc and incandescent lighting dynamos. Dynamos were much the more important. Until about 1883 - 5 arc lighting equipment ought to be treated as a rather distinct product.

The Manufacture of electrical machinery was rather slow to start in England. As the names Jablochkoff, Lontin, Gramme, Brush and others reveal, most of the arc lighting equipment used in the very early days was manufactured abroad. In 1878 there were only two firms manufacturing dynamos in Britain, Siemens, itself the English part of a largely German firm, and Henry Wilde in Manchester. In 1879 and 1880 a few more firms entered this business, notably Crompton, but until Brush began to make arc lighting equipment in this country imports must have been a very large proportion of the home consumption of machinery.

After that, however, many home firms began to make electrical machinery. They can be divided into three major groups. Firstly there were those who were existing telegraphic manufacturers. Secondly there were new firms founded on particular inventions - often made by people utterly unconnected with electricity. Thirdly there were mechanical engineering firms.

Of the first group, those with a scientific connection with electric lighting, the only really successful entrant was Siemens. Siemens had been to the fore in dynamo improvement. In 1867 and again in 1873 the German part of the firm had been responsible for major innovations. It was not surprising that Siemens gained first place in the Trinity House dynamo tests of 1877. Stimulated by the possession of a first rate dynamo, Sir William Siemens, head of the London branch, made several improvements in arc lamps in the late 1870s. He determined to apply arc lighting to the lighting of large spaces as well as lighthouses. Siemens arc lights soon began to appear, and in 1881 Siemens was one of the four companies to tender for the important lighting, proposed for the City - at a considerable loss. But Siemens did not foresee, as far as we can tell, any very rapid expansion of electric lighting. The engineering of the system was directed more perhaps towards a high quality than a low cost lamp. The early arc lamps did not give a very pleasant light.

1. See Chapter 1 P. 2.


3. Siemens charged £3,725 and in the first year lost £2,246 on this contract. They cost a similar sum on the Albert Dock lighting which they installed in 1879 (Elect. 27 May 1882, & Siemens Bros. accounts.)
Siemens improved them and produced perhaps the least unattractive of arc lights. But to do this he used a low voltage giving a small arc. This made current control more difficult, and thus increased the difficulty of running several lamps from one dynamo. In other ways Siemens were noted for their high engineering standards. Wires were laid underground; in many ways this was admirable but it was expensive. This is not to say that Sir William Siemens was uninterested in the commercial prospects of arc lighting. He saw that it was at a relative advantage when high powered lights were used. Siemens arc lighting was intelligently placed on high poles. But at least, as his biographer states, Sir William, by the seventies was moving away from commercial interests towards more purely scientific matters.

Another important cable manufacturer to take up the manufacture of dynamos and arc lamps was the India Rubber and Gutta Percha Co. They seem to have begun with the manufacture of arc lamp carbons. However, although they continued to make dynamos up to 1914 they were never very important. The Telegraph Construction and Maintenance Company, another large telegraph manufacturing firm founded an electric light department in 1881. It was set up under J.E.H. Gordon, a young man of 30 with a background of scientific research. Gordon built a 350 KW alternator, with three times the output of any machine then constructed, to light the company's works. He soon became interested in central station work. The Chairman of the Telegraph Construction and Maintenance Co. Sir Daniel Gooch, who was also Chairman of the Great Western Railway, believed in

Gordon, and in 1883 it was resolved to begin work on a scheme to light Paddington Station, the G.W. Hotel and neighbouring goods yards and lines. With over 4,000 incandescent lamps and 100 arc lamps it was said to be the biggest installation of mixed lighting hitherto made. Unfortunately there were very considerable teething troubles, and Gordon himself was so disappointed with the results that in 1888 he said he was prepared to abandon his own system and every patent he held. The Telegraph Construction and Maintenance Co. seems to have felt much the same about electric lighting in any form and when this installation was sold to the G.W.R. in 1887 they left the electric lighting field.

The only other telegraph manufacturer to begin the manufacture of electrical machinery at this time was the small partnership of Johnson & Phillips. First they made arc lamps but soon built generators as well. Later they added switchgear, transformers, motors to their range. But they remained primarily concerned with cables and their share in the market for electrical machinery was small.

The second class of firm was that founded on particular inventions. Most of the early electric lighting inventors sold their patent rights to a firm. Many firms were founded to buy those patent rights and manufacture the new product. In the early 1830s the inventions were often foreign.

1. ibid., p. 44.
2. ibid., p. 48—for details.
The failure rate was high among this type of firm. All systems of lighting in the early eighties had serious practical difficulties; these firms were often without adequate technical knowledge and the quality of general management was often poor. The most successful of these companies was Brush, but even Brush had its flaws. As has been pointed out it had the best of the early arc lighting systems. As a result of this it seemed very prosperous at first. 1881 was a very good year. 1881 & 2, the company was also able to sell concessions for the exclusive right to sell Brush equipment in various parts of the country for high prices. The first half of 1882 seemed so prosperous that in the summer an interim dividend of 100% was declared. Manufacturing facilities were more than doubled yet as we have seen the boom soon collapsed.

The rapid expansion of 1882 showed up considerable weaknesses in the management of Brush. The manufacturing profit fell from £35,464 in 1881 to £33,713 in 1882 although turnover more than doubled. As early as July 1882 there were doubts about the quality of the management. R. Hammond, who as one of the early purchasers of concessions was in a knowledgeable position, wondered whether manufacturing was not running at a loss. At the meeting of January 1883 there were accusations of bad management which were not very satisfactorily answered. Meanwhile sales were falling rapidly, Brush being worse hit than the other major companies by the collapse

1. Chapter 1. PP 11 - 12.

2. Fixed assets rose from £25,013 in December 1881 to £66,490 in December 1882.


of the boom. By May 1883 the Brush Chairman resigned and the Board
was reconstructed. A considerable reorganisation of the Company
followed. A new General Manager and Secretary was appointed. Costs
were thoroughly investigated and substantial economies made. It was said
that general expenses were reduced by 50%. Asset values were also sharply
written down.

Policy was changed in two directions. Firstly the company was
no longer to rely on arc lighting alone. The concessionary companies
formed in 1882 had complained about the lack of an incandescent lighting
system in the patents they bought. In 1882 Brush had sought to remedy this
by buying for £50,000 the patents of Lane-Fox. But they did little with
them at first except come to arrangements with their concessionaries to
sell Lane-Fox incandescent lamps as well as arc lighting equipment. But
after the reorganisation Brush began to devote more attention to incandescent
lighting. In 1883 W.M. Mordey, the company's chief electrical engineer
started work on a dynamo for incandescent lighting. In 1884 he produced
the successful Victoria dynamo. Incandescent lighting equipment soon
became important, as is shown in Table 56.

Secondly the company saw that central stations were no longer
going to develop rapidly. It therefore repurchased concessions where these
were for the exclusive marketing of Brush equipment in various parts of the

1. Elect., Vol. 11, P1. 19 May 1883.
3. The New Secretary was E. Garke. Garke was born in Germany in 1856.
   In 1887 he became manager of Brush. In 1891 Managing Director. In
   1893 he resigned from Brush and became Managing Director of the E.C.C.
   He left E.C.C. in 1894 and from then onwards was principally concerned
   with British Electric Traction.
Table 58.

Brush Sales of arc and incandescent lighting equipment.

<table>
<thead>
<tr>
<th>Year</th>
<th>Value of sales of arc lighting equipment</th>
<th>% of total sales</th>
<th>Value of sales of incandescent lighting equipment</th>
<th>% of total sales</th>
</tr>
</thead>
<tbody>
<tr>
<td>1885</td>
<td>14,909</td>
<td>23.2</td>
<td>19,438</td>
<td>37.4</td>
</tr>
<tr>
<td>86</td>
<td>6,713</td>
<td>11.4</td>
<td>17,040</td>
<td>37.1</td>
</tr>
<tr>
<td>87</td>
<td>10,908</td>
<td>14.0</td>
<td>13,980</td>
<td>26.8</td>
</tr>
<tr>
<td>88</td>
<td>25,545</td>
<td>23.7</td>
<td>17,037</td>
<td>24.2</td>
</tr>
</tbody>
</table>

Source: Historical records of Brush Electrical Engineering Co. Loughborough.

country. So Brush returned to contracting work, often itself installing its own plant for customers.

An example of a very poor performance by a firm founded on patent rights is that of the Electric Light and Power Generator Company, later the Maxim-Weston Electrical Company. They began by getting the contract for arc lighting in one part of the City, using Lontin arc lamps; they lost £4,000 on a contract worth £3,000. They then bought the Maxim incandescent lamp patents, a useful asset. In 1881 Maxim came to Europe to investigate the use being made of his patents. The U.S. Electric Lighting Co., which held the Maxim patents in the U.S. considered that the London Company was not making enough progress. In his autobiography Maxim tells us what he found at the Bankside factory of Maxim - Weston.

"I have never seen anything like it in my life. The place was unspeakably dirty, everything was so out of order that we were tripping over copper wires everywhere; the windows were so thick with dust that they admitted little light; and the few men at work wore burning gas out of the open end of the pipe without any burner. In walking about the place I saw a high priced Brown and Sharps milling machine. It was smothered with dirt
and appeared to be in a very delapidated condition. The roof was leaking and the machinery had been rained on and was slightly rusty in places."

Only four or five men were employed in the factory; Maxim offered his services; he was offered a guinea a year.

The company after their unprofitable time with Lentin arc lamps bought the patents of Edward Weston. These patents cost large sums of money.

By March 1933 £113,800 had been spent on patents, as against only £2,391 on fixed plant and £21,373 on stock. Also large sums had been spent in 1882 on lighting installations. £4,405 had been lost on the City lighting, £1,225 on the Metropolitan Railway lighting, £382 at the Edinburgh Post Office and £26 on what had been thought to be a good contract at the Botanical Gardens, £1,868 had been spent on exhibitions. But all this had bought them no business - by May 1884 the loss over the previous two years was £32,284. Business improved a little after that and small dividends were paid beginning in 1885. Yet it is not clear that profits were being made, for in 1888, when a new board of Directors took over the auditors discovered that assets were valued at £17,445 in excess of their true value of £24,723. Trading results had not been truly stated in the past.

The making of losses by Maxim-Weston was, considering the circumstances of the time not significant. But they were very large losses, the firm was obviously badly managed. It was run by business men, not engineers, and what business men meant in this case was people with


2. For the work of Edward Weston see H.C. Passer. op.cit. PP 31 - 34.

3. The above is based on reports and meetings of the Maxim-Weston Electrical Company given in the Electrician and the E.R.
experience in buying and selling. Patents were to a large extent treated as a commodity. There was no serious attempt to manufacture plant, although the company had a small factory. Thus the firm was usually one step behind with technical progress. For example it announced with delight in 1885 that the U.S. Electric Lighting Co. had decided to stop using Maxim dynamos and lamps (because they were obsolete). The English firm was thus able to buy large quantities at low prices.

More examples of this type could be given. It is surprising how many good patents found their way into incompetent hands. There was often poor co-operation between inventor and company, and inventors rarely did more than sell the patents.

The third type of firm beginning the manufacture of electric lighting plant in the early eighties was the mechanical engineering firm. In many ways they were the most successful group. Electrical machinery was much heavier than telegraphic equipment, dynamos had much in common with other rotating plant like steam engines and machine tools.

There were three important entrants from mechanical engineering in the 1880s. The first was Crompton & Co. R.E.B. Crompton was an ex Indian army engineer who was a partner in a small mechanical engineering firm in Chelmsford. He came to the manufacture of electrical machinery almost by accident. He was supervising the building of a foundry in 1878 and experimented with new methods of casting pipes. The work got behind

1. Crompton formed a series of partnerships. Crompton & Albright was the principal one in the 1880s. In 1888 it was turned into a joint stock company. I shall simply speak of Crompton & Co. (or simply Crompton) throughout.

2. See Chapter 1 P 16.
and to hurry it Crompton decided to try the new arc lighting. He decided to manufacture arc lighting equipment himself because it seemed useful and because of deficiencies in the Gramme equipment. At first he merely improved the arc lamp, but when he heard that Brush and Wallace Farmer in the United States were using several arcs on a series circuit he set out to copy them. At first he used the Gramme dynamos at a high speed to give the necessary voltage but mechanically it was not adequate for this. Together with a Swiss, Emilie Burgin, he designed a new high voltage dynamo. He needed more space to manufacture it and the old partnership was dissolved and Crompton took over the whole works. By December 1880 the first Crompton-Burgin dynamo was ready, capable of providing current for 6-8 arc lamps. Crompton arc lighting, although behind Brush in the number of lamps run from one dynamo, soon became successful. The works at Chelmsford soon had to be extended and by 1881 Crompton was said to be one of the three most important firms, together with Brush and Siemens. But output was probably less than that of the other two.

Crompton seems to have been the first electrical manufacturer to make machinery specifically for incandescent lighting. In 1880 Crompton began the manufacture of dynamos for Swan lamps, and in 1881 and 1882 when a number of installations were made of Swan lamps, Crompton supplied many dynamos.

Although a firm with less financial resources than Brush or Siemens, Crompton was sufficiently optimistic about the future of electric lighting to be involved in a scheme for a central station in Birmingham. Most of the money was to be supplied by Winfield & Co. manufacturers of brass work, chandeliers, etc. but Crompton was supply the machinery. But the scheme failed, Winfields went into liquidation and Crompton lost a lot of money.

The second entrant of this type was Mather & Platt Ltd. It was a long established firm and in the seventies it was principally engaged in the manufacture of textile finishing machinery. In the eighties under the direction of Sir William Mather, three important new lines of manufacture were started. Two were as a result of a visit by Mather to the U.S.A. in 1882-3. There he acquired the English patent rights of the Edison dynamo and the Ginell sprinkler. As a result the company began an electrical department and an automatic fire protection department. Mather also started a pump department based on the development of the designs of Professor Osborn Reynolds of Owens College for centrifugal pumps.

The new electrical department had first rate technical advice.


2. Born 1838. 1855 articled to his father's and uncle's works, 1858 he became assistant manager. Visited Russia and the Continent 1859-63 and American 1882-3. He was the first Chairman of the Castner-Kellner Alkali Co. in 1895. He was the Chairman of the Chloride Electrical Storage Co. (battery manufacturers) from 1891-1896. (see Sir W. Mather. Ed. L.E. Lather. London 1925?)

3. The antifire sprinkler was invented by F. Ginell of Providence, Rhode Island.
John Hopkinson, Professor at Owens College was appointed consulting electrical engineer. He redesigned the Edison dynamo according to scientific principles. A machine for 150 lights after being remodelled and constructed according to Hopkinson's principle was capable of supplying current for 250 lights. Together with his brother Edward he designed the "Manchester" dynamo and motor in 1884. The Edison-Hopkinson and Manchester dynamos, with later modifications were the main products of Mather & Platt's electrical department right up to 1900.

Another important, but at first very small electrical machinery manufacturer emerged out of mechanical engineering in 1882. This was the partnership of Elwell-Parker. One of the partners was Thomas Parker. Born in 1843, he had been employed by the Coalbrookdale Company from the age of 9, and had become the manager of the engineering side of the business. Throughout the late seventies and the early eighties he had been interested in dynamo design. In 1882 he joined Bedford Elwell who was in business in Wolverhampton as a Patent Tip and Horse Shoe Company. An electrical department was started, which, at first employed only three men, but expanded rapidly after 1885.

During the middle and late eighties a number of established mechanical engineers added an electrical department. Also a number of

1. Born 1849. Died 1891. An extremely good mathematical engineer. At Cambridge he was Senior Wrangler in 1878 and first Smith's prizeman. In 1871 he became a F.R.S.
3. See Chapter 5 P. 194.
4. Electrical Times Vol. 59 PP 405 - 408 28 April 1921. The Early days of the Electrical Industry.- the E.C.C.
small partnerships with a general engineering background began to make electrical machinery. They usually made only dynamos for use with the lamps of other manufacturers. An important reason for this was the emergence of principles of dynamo design. In the early eighties the design of electric lighting machinery was a question of inspired empiricism. Until 1881 there were no standardised units of electrical measurement and instruments were primitive in the extreme. Crompton was said to design dynamos by looking at them. Changes in arc lamps involved changes in dynamos. If pieces of equipment were put together which were not designed to be run together a large number of incalculable adjustments would have had to be made. But by 1882 much more was known scientifically, and it was less necessary to treat arc lighting equipment as a unit. Nevertheless it tended to be so treated until well into the 1890s. In the case of incandescent lamps, the situation was different from the early days. Swan made only light bulbs and relied on dynamos bought from outside. In 1880 he used both Crompton and Siemens dynamos, and from 1883 onwards Edison-Swan bought a number of dynamos from Lather and Platt.

Once the principles of dynamo design were known, other mechanical engineers started to produce them. From an engineering point of view this was to be expected. They had experience of non-electrical rotating plant, steam engines, machine tools etc. and this gave them advantages, as many of the difficulties with early dynamos were mechanical as well as electrical. They rotated quite rapidly for the state of engineering knowledge.
Clearances had to be quite small between armature and field coil for the efficiency of the machine to be high. Although machines were tiny by later standards - under 50 KW for most of the eighties - these were much bigger loads with correspondingly greater mechanical strains than were involved with telegraphic apparatus. Fowlers of Leeds, makers of steam engines and agricultural machinery, Greenwood and Battey, engine builders, W.H. Allen, also engine builders, Clarke Chapman, marine and general engineers, were among the established general engineers who started small dynamo departments in the middle and late 1880s.

The possibility of using electric motors in factories attracted more mechanical engineers, especially those already making rotating tools driven by steam engines or shafting. Often a special motor was needed for a special tool. There was scarcely any electric power in the late eighties but one firm of mechanical engineers at least, Easton Anderson and Goolden saw the possibilities of electric cranes as early as 1888. They were formed by the amalgamation of Easton and Anderson with the small firm of dynamo builders, W.T. Goolden & Co.

During the eighties electrical machinery manufacture was highly concentrated. Table 59 gives what figures can be collected of the gross output of four of the major firms in the 1880s. The only major firm entirely omitted is Elwell Parker during the second half of the eighties. It is doubtful if its turnover was bigger than that of Hather and Platt's electrical department. Brush Siemens and Crompton seem to have had a very large share of the market in the early eighties. After 1882 their share seems to have declined, but they remained very important. It is not likely that the aggregate output of the small firms was very large.
### Table 59.

**Gross output of electrical machinery.**

<table>
<thead>
<tr>
<th>Year</th>
<th>Brush</th>
<th>Siemens</th>
<th>Mather &amp; Platt</th>
<th>Crompton</th>
</tr>
</thead>
<tbody>
<tr>
<td>1880</td>
<td>/</td>
<td>18,360</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>80,000</td>
<td>35,840</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>200,000</td>
<td>85,780</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>35,000</td>
<td>71,439</td>
<td>1,191</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>48,771</td>
<td>73,985</td>
<td>4,848</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>59,722</td>
<td>N/A</td>
<td>6,337</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>54,085</td>
<td>10,034</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>70,741</td>
<td>14,400</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>.98,629</td>
<td>17,041</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>23,313</td>
<td>rate of 70,041</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. Excludes incandescent lamps.

2. If we include production at the Brush factory in Austria output is £80,746 and £115,629 for 1887 and 8.

3. Estimated from output in KW.

In the case of incandescent lighting dynamos in the middle eighties we have quite good information about market shares. Brush held important patents covering the best method of winding constant voltage dynamos. They were willing to issue licences if a royalty of 10/- per KW (5 - 10% of contemporary prices) was paid. The only major firm to refuse was Crompton. If we assume—on literary evidence—that Crompton's
output of incandescent lighting dynamos was equal to that of Mather & Platt, Table 60 can be constructed.

Table 60.

<table>
<thead>
<tr>
<th>Shares of the market for incandescent lighting dynamos</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>early 1886 - end 1887</td>
<td></td>
</tr>
<tr>
<td>Brush</td>
<td>30</td>
</tr>
<tr>
<td>Siemens</td>
<td>19</td>
</tr>
<tr>
<td>Crompton</td>
<td>16</td>
</tr>
<tr>
<td>Mather &amp; Platt</td>
<td>16</td>
</tr>
<tr>
<td>Elwell-Parker</td>
<td>11</td>
</tr>
<tr>
<td>India Rubber &amp; Gutta Percha</td>
<td>3</td>
</tr>
<tr>
<td>Manchester &amp; District</td>
<td></td>
</tr>
<tr>
<td>Edison-Swan</td>
<td>2</td>
</tr>
<tr>
<td>Others</td>
<td>1/4 and less</td>
</tr>
</tbody>
</table>

The arc lighting equipment market seems to have been more concentrated. Literary evidence suggests the manufacture of arc lighting equipment was primarily in the hands of Brush, Siemens and Crompton. By 1883 the three principal firms were making multi-arc dynamos; Siemens and Crompton made them for up to 12 lamps, Brush for up to 40. By 1889 the number had risen to 28, 30 and 55 respectively. The lamps had been standardised at about 45 - 50 volts, and were now built to burn up to about 15 hours. Siemens had thus followed Crompton in producing a system
like that of Brush. Arc lighting, however, never developed in this country as it did in the United States. This was partly because it was little used in the streets. Arc lighting equipment was a declining share of Brush output 1885 = 8, and we may assume both that this was true of Crompton and Siemens and that the percentage continued to fall.

The collapse of the boom of 1882 adversely affected all manufacturers of plant, although the magnitude of the effect varied very considerably. Brush, the one who had expanded the most was the worst affected. The company employed 800 men in 1882, and by 1886 the number had fallen to 300. Siemens' output fell by only 15%. Crompton who did not expand in 1882, doubled the size of his works in the depression year of 1883, and further expansion took place in 1884. This rise in output seems to have been due to Crompton's concentration on expanding the demand for isolated plant. Siemens soon followed, and then Brush. By 1885 demand had risen enough to keep the principal factories fairly busy. Crompton was doing particularly well and was even able to keep a night shift going.

The value of output by 1885 was, however, well below that of 1882. Prices had fallen very sharply, partly because of the sales of equipment of firms going into liquidation. Even though the aggregate amount of plant sold for this reason was small demand was inelastic in the short run.

This factor was said to be particularly important in 1886 when prices fell sharply. Price data are sparse and difficult to interpret because of the varying sizes of equipment. But one commentator stated that the price per kW of an 80 kW incandescent lighting dynamo was £29 in 1882 and only £6 in 1887. Other data is consistent with this. The fall went on all through the period 1882-83. Brush arc lighting dynamos sold in 1885 at an average revenue of £174; by 1888 average revenue was only £113. The average revenue of Brush incandescent lighting dynamos fell from £125 in 1885 to £112 in 1888. But the size of dynamo was probably rising and this would cause the fall in price to be underestimated.

Brush arc lamp prices, where there is no size ambiguity fell from £11.4 in 1885 to £8.1 in 1888.

Low prices and low demand, particularly the absence of demand for Central station plant drove English manufacturers to wider markets. Crompton seems to have led the way here. In 1883 the Ring Theatre in Vienna was destroyed by fire and it was decided to try electric lighting in the new theatre. The job to be done was bigger than anything attempted in England; for example the generating station was a mile from the theatre. Crompton's scheme, using Willans - Crompton generating sets and a 5 wire d.c. distribution was a forerunner of the London stations of c.1890 and the first instance of the very successful British practice of direct coupled engines and dynamos. By 1886 the plant was working and Crompton went in search of more Continental orders. In the next few years he visited

2. Brush Historical Records.
Gothenburg, Stockholm, Copenhagen, Belgrade and Sophia. But he got few orders and in his autobiography states that this was because of the credit facilities given by the German banks who backed the German electrical manufacturers. British bankers refused to give him credit to be extended to his customers. In 1886 Brush, whose sales to the Continent had been "hampered by high tariffs and great competition in North Germany" bought a factory in Vienna. In 1887 and 8 the output of the Vienna factory was about 10% of the total Brush output.

Because of its connections with Siemens & Halske, Siemens did not seek markets abroad. Siemens seems to have withdrawn from electric lighting more than other firms. This may have been partly due to the death of William Siemens in 1883. It must also have been due to the high level of demand for submarine cable and its considerable profitability during the 1880s. The Electric light department showed regular losses from 1880 - 84 except for 1882 when a very small profit was shown. The departure of Edward Hopkinson in 1893 may be a farther indicator of a contraction of interest in the field.

Total exports of electrical equipment were substantial. The figures in the statistical abstract relate to all electric lighting apparatus. But it is possible to make a guess at the gross output of

2. See J.D. Scott, op. cit., PP 64 - 5.
Table 61.

Siemens Bros. The Electric Light Dept. Net profit as a percentage of sales and stock.

<table>
<thead>
<tr>
<th>Year</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1880</td>
<td>-33.5</td>
</tr>
<tr>
<td>1881</td>
<td>-22.2</td>
</tr>
<tr>
<td>1882</td>
<td>+0.7</td>
</tr>
<tr>
<td>1883</td>
<td>-3.8</td>
</tr>
<tr>
<td>1884</td>
<td>-4.3</td>
</tr>
</tbody>
</table>

Losses include losses on lighting installations which were heavy 1880 - 2.

Source: Siemens Bros. Historical Records.

1 electric lighting plant. In 1886 exports were roughly 30% and in 1888 roughly 35% of production. Imports were not recorded in any satisfactory form until 1903.

1 The output of Brush and Mather & Platt is given in Table 59. An estimate for Siemens and Crompton is taken from the level of their sales at other times. I assume Elwell-Parker output was the same as that of Mather & Platt. Let us assume that these firms had the same share of the market for machinery that they had for incandescent lighting dynamos. Edison-Swan output of incandescent light bulbs is known. Let us assume they had a 75% share of the market in 1886 and a 90% share in 1888. The resultant estimates of gross output are £310,000 in 1886 and £491,000 in 1888. This does not include the output of cable firms, but cables exported except as part of assembled electric lighting plant would be separately enumerated. Cables sold other than as part of electric lighting equipment would be excluded from production and exports and cable sold as part of electric lighting equipment included in both.
The second cycle in the demand for electrical plant is from 1888 to 1895. There was a big upswing from 1888 to 1891 as central station supply at last began. The value of output of electrical machinery seems to have roughly trebled. After 1891 the value of output seems to have continued to rise, although at a much slower rate. What figures we have however suggest that it may have risen by as much as 15 - 20% between 1891 and 1895. But it was not a steady rise. From 1891 - 5 prices fell sharply and there was probably a fairly considerable rise in the volume of output.

The boom brought about a considerable expansion both of the number of producers, and of the major firms. The market continued to be highly concentrated. Five firms supplied the bulk of the traction equipment for the new central stations. We have figures of dynamos installed by makers measured in KW, and because it was at that time the usual practice to award the contract for all the electrical equipment, except the cables, of a central station to one firm the figures are reliable indicators of the market shares of the firms for all central station electrical machinery. Later figures are in Table 80 P 396.

The beginnings of central stations also made for changes in machinery. The only major change was a rise, not a very large one, in the size of dynamos. Home manufacturers took this in their stride. Some, like Crompton had already been making central station plant for
Table 62.

Manufacturers of electrical machinery
1882 - 1899

<table>
<thead>
<tr>
<th></th>
<th>1882</th>
<th>1884</th>
<th>1886</th>
<th>1890</th>
<th>1893</th>
<th>1895</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dynamos</td>
<td>16</td>
<td>19</td>
<td>94</td>
<td>72</td>
<td>79</td>
<td>69</td>
</tr>
<tr>
<td>Motors</td>
<td>2</td>
<td>15</td>
<td>27</td>
<td>45</td>
<td>48</td>
<td>49</td>
</tr>
<tr>
<td>Arc Lamps</td>
<td>16</td>
<td>27</td>
<td>44</td>
<td>52</td>
<td>51</td>
<td></td>
</tr>
<tr>
<td>Transformers</td>
<td>11</td>
<td>23</td>
<td>24</td>
<td>21</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Meters</td>
<td>2</td>
<td>5</td>
<td>11</td>
<td>20</td>
<td>22</td>
<td>18</td>
</tr>
<tr>
<td>Traction Equipment</td>
<td>1</td>
<td>4</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The data have been taken from a Buyers Guide. Whenever possible agents supplying equipment made by other firms have been excluded but it is not possible to guarantee that this has been entirely done. The method of classification has overlapping categories, and in some cases apparently similar categories contain markedly different numbers of firms. This has been allowed for as much as possible.


Table 63.

Dynamos installed by 5 principal firms in Central Stations up to the end of 1892.

<table>
<thead>
<tr>
<th></th>
<th>kW</th>
<th>% of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>E.C.C.</td>
<td>1100</td>
<td>10</td>
</tr>
<tr>
<td>Brush</td>
<td>1000</td>
<td>16</td>
</tr>
<tr>
<td>Siemens</td>
<td>916</td>
<td>15</td>
</tr>
<tr>
<td>Lathor &amp; Platt</td>
<td>942</td>
<td>15</td>
</tr>
<tr>
<td>Crompton</td>
<td>842</td>
<td>14</td>
</tr>
</tbody>
</table>

Source: See Table 80.
Table 64.

Crosa output of the major firms 1888 - 96. £000

<table>
<thead>
<tr>
<th>Year</th>
<th>Brush</th>
<th>Siemens</th>
<th>Crompton</th>
<th>E.C.C.</th>
<th>Mather &amp; Platt</th>
</tr>
</thead>
<tbody>
<tr>
<td>1888</td>
<td>125</td>
<td></td>
<td></td>
<td></td>
<td>17</td>
</tr>
<tr>
<td>1890</td>
<td></td>
<td>70</td>
<td></td>
<td></td>
<td>23</td>
</tr>
<tr>
<td>1891</td>
<td>223</td>
<td></td>
<td></td>
<td>4</td>
<td>27</td>
</tr>
<tr>
<td>1892</td>
<td>200</td>
<td>83</td>
<td>125</td>
<td>130</td>
<td>15</td>
</tr>
<tr>
<td>1893</td>
<td>235</td>
<td></td>
<td>124</td>
<td></td>
<td>21</td>
</tr>
<tr>
<td>1894</td>
<td>294</td>
<td>120</td>
<td>150</td>
<td>97</td>
<td>22</td>
</tr>
<tr>
<td>1895</td>
<td>258</td>
<td>142</td>
<td></td>
<td>115</td>
<td>19</td>
</tr>
<tr>
<td>1896</td>
<td>258</td>
<td>144</td>
<td></td>
<td>126</td>
<td>39</td>
</tr>
<tr>
<td>1897</td>
<td>140</td>
<td>184</td>
<td></td>
<td>127</td>
<td>102</td>
</tr>
</tbody>
</table>

+ Estimated from size of stocks plus work in progress and statistics of capital: output ratio.

1. Includes engines and tramway rolling stock after 1890.

2. Dynamo department output.

3. Estimated from KW figures at an average revenue of £10 per KW. A.R. data for Mather & Platt machinery support this.

4. Includes E.P.S. Storage batteries, and may include sales of "paper".

Sources: Brush Historical Records
Siemens Historical Records
E.C.C. Historical Records
Crompton Historical Records
Mather & Platt name plate books
Various statements at company meetings.
export. The increasing size and weight of electrical machinery was part of the reason for the Brush move. The heavier work was to be done at Loughborough and the lighter work in London. It is also shown by the expansion of Elwell-Parker into new and large works, into a factory from workshop.

The other major way in which the 1888 - 1895 cycle differed from that of 1879 - 1887 was that the boom was successful in launching electric lighting, and as a result of this there was no catastrophic recession. The building of the early municipal central stations indeed led to a continued increase of demand. Yet the falling prices of 1891 - 5 in some ways seemed to do more damage than the collapse of 1883. For during the middle nineties the British electrical machinery makers began to fall technically far behind the Americans and the Germans in engineering progress. In the late eighties and early nineties they were not backward; the change seems to have come very quickly. As we saw in Chapter 2 they showed considerable ingenuity in designing the early London central stations. Outside London the E.C.C. built successful central stations for Oxford and Wolverhampton on the high voltage d.c. system. Although not the right solution to the electricity distribution problem it was well worth trying. In 1892 J.S. Raworth of Brush made a very important innovation in switchgear. He placed switches in metal pillars for the Wandsworth station of the County of London Co. Faulty switches were common at the time, and more than one central station was

very severely damaged by fires caused by arcing at switches. The Raworth pillar was the forerunner of the metal-clad switchgear used with great success from 1905 onwards. Several very good electrical and mechanical engineers worked for the manufacturing companies. J.S. Raworth, W.M. Mordey, R.E.B. Crompton and Thomas Parker were all first class engineers.

However by the late nineties the E.C.C. and Crompton and Co. had quarrelled with Parker and Crompton. Mordey and Raworth had left Brush. English manufacturers made no attempt to develop traction equipment after 1891, despite their good start. The great new development in the early nineties, polyphase a.c., they ignored entirely.

Some explanation for this is to be found in the workings of the recession of 1891-5, some in the nature of the capital market, and some in the workings of joint-stock companies at the time.

The recession was in prices and not in output, and this fall in prices is at first rather surprising when demand was growing, especially as there is no real evidence of overcapacity at the end of the boom.

On the average the major firms seem to have been fairly fully employed by 1891, and in the following years slightly expanded capacity to allow for rising output. The number of producers rose sharply from 1887-90 but not afterwards. There is no good evidence about the activities of the

1. ibid., pp 26 - 7 and 77.
3. English manufacturers also exported plant. Both Brush and Crompton invested in Australian branches. Those became very unprofitable with the Australian depression which began in 1891. Demand was nevertheless dominated by home demand.
small firms and firms with a small electrical department, but what does exist suggests that output was rising 1891 - 4 and that they were working close to capacity. Despite this contemporaries noticed "unreasonable price cutting". As early as 1893 the Electrical Review had a special leader on the state of the electrical industry commenting,

"in spite of the rapid extension of electric lighting and the abundance of work ..... we really question whether the state of the industry was ever more unsatisfactory than it is at the present moment .......... Although most workshops are fully employed competition is responsible for the cutting down of prices to such an extent that the narrowest margin of profit is left; .... in many instances the acceptance of tenders must have resulted in actual loss ..... a few days ago a well known dynamo maker remarked that his firm considered when tendering that if they added 10% to the total works cost of a dynamo they would expect to lose the order." 2

Electrical plant was usually built to order. This was true of work for isolated plant as well as central stations. An individual order was often large relative to the output of a firm. An extreme example is provided by the Brush contract for the City of London Co., begun in 1891. It was worth over £300,000 when the firms average annual output was about £250,000. With intermittent large orders queueing theory leads one to expect either very long delivery dates or that firms would find some part of their capacity unemployed periodically. Capacity does seem to have been high enough to keep delivery dates fairly short - i.e. not much longer than the average time of manufacture at something approaching a maximum

rate of work. Also references in company reports do suggest short term variations in the degree of utilisation of capacity.

Costs varied little with short term fluctuations in output. Capital costs fell only slightly as work in progress fell. Labour costs fell little as skilled labour was largely employed, and could not be varied in quantity in the very short run. Thus when capacity was underutilised there was a temptation to quote low prices.

If prices were falling for this reason one naturally wonders why capacity should be rising. But the technique of production coupled with large irregular orders provides an answer. Electrical machinery was made by skilled labour with relatively simple multi-purpose machinery in large erecting shops. Building a new shop was expensive but once one existed its possible throughout capacity could be simply and cheaply extended by adding a few extra machines and using the floor space more intensively. A firm would not hesitate to tender for a contract which required slight additions to capacity of this kind. Once it was created firms would wish to use this capacity which could then exercise a dampening influence on prices.

These factors were reinforced by the fact that successive jobs differed widely. Small improvements were continually taking place in

1. This concept is unfortunately far from precise. But all that is implied here is that, given usual techniques of production, a piece of machinery took (roughly) a minimum time to manufacture. This time could not be reduced without a change in technique because of limits on the number of men who could work simultaneously on it and the traditional limits to the working day. In the absence of any detailed evidence it would be fussy to worry too much about precision.

2. There are too many difficulties in figures of capital employed and too few output figures for one to be able to say much about the importance of capital costs. The fixed capital and stocks: output ratio seems to have been about 1.5. The Capital: stock: output ratio seems to
design. Firms undertook a wide range of jobs and there were few jobs in the aggregate. Also customers often had firm views about the specifications for a job and they usually differed from each other. Thus the cost of a job could not be foreseen accurately. Under pressure firms were optimistic about costs.

There was a change in the method of selling plant to central stations in the first half of the nineties which intensified the forces which could lead to low tendering. In 1888-91 an electricity supply company ordered all or nearly all of its initial plant from a manufacturer. The latter was largely responsible for the design of the plant, and subcontracted for items he did not wish to manufacture. Sometimes the engineer to the supply company was also a manufacturer, two notable cases being Crompton and Ferranti. But this system soon gave way to the techniques of employing a consulting engineer. He designed the plant and specified more or less closely the desired operating performance of the equipment, for example the efficiency of transformers at varying loads and the steam consumption of generating units. The tradition became quickly established that these consulting engineers should be independent of the manufacturers. Naturally there was a period of transition. In 1893 the Electrical Review commented several times on the alleged connections

between consulting engineers and manufacturers. But by 1895 they do
tend to have become independent. The change was largely, the result
of the beginning of municipal electricity supply.

The change had two important effects. In the first place
specifications became more detailed. Variations in the operating costs
of the machinery of different makers were thus substantially reduced.
In order to get the plant with the lowest total costs (capital and operating)
buyers could simply choose the lowest tender. Competition between firms
moved in the direction of more price competition, away from product competition.
The distinction is one of emphasis; too much can be made of it but it is
plausible to suppose that in fact if not in logic price competition would
reduce profits much more rapidly in the short run.

In the second place closer specifications, together with the
attitude of municipal purchasers in particular, brought in the apparatus
of guarantee and penalty clauses. Municipalities generally mistrusted
companies operating for profit. Much of the work commissioned by
municipalities in the past was building work where they had been confronted
with local monopolies. Thus they had stiff contract terms, one of the
important clauses being that the corporation's engineer should be the

1. There was adverse comment when R. Hammond became a consulting engineer.
The Electrical Review complained that "he cannot pose as an independent
consulting engineer; he is still openly connected with the manufact-
turing and contracting departments of 4 or 5 different companies."
E.R., Vol. 33 P 241. 1 September 1893. It was also alleged that
Hammond's connections with J. Fowler & Co. led to the acceptance of
sole judge in disputes between contractors and the corporation. Penalty clauses were strong. This type of contract was applied to the building of electricity supply stations, where sellers had much less monopoly power. The machinery manufacturers were not in a position to resist these clauses. In their situation one would expect the propensity to accept them to be stronger than that to offer lower prices. Possible penalties could seem a long way away. Yet if the firm failed to meet its guarantee it could be very expensive. This factor often lowered profits even though it did not lower prices.

Even though electrical machinery manufacture was highly concentrated, firms did not in any way act together to keep up prices. On the contrary they cut prices as soon as there was a possibility of working under capacity. Crompton in particular became somewhat notorious for tendering low prices. At the annual meeting on 9 August 1896 one of the shareholders remarked that he heard a good deal about electrical business in the City, and he had been informed that of all firms that went in for cutting contracts Crompton and Co. were the very worst. To this Crompton replied that it was difficult for any firm to get profitable contracts unless they took financial risks. The Chairman declared that business could not be obtained unless the tender was very low.

There was another important reason, in addition to those discussed above for the fall in prices 1891–5. This was the state of mechanical

Many of the firms entering the market for electrical equipment in 1838-90 were established mechanical engineers, who added an electrical department. In 1889 and 1890 the *Economist* reported that mechanical engineering was very busy and prosperous. Then prospects began to wane and 1893 was a year of "particular anxiety and depression." In most branches manufacturers were working well below capacity. Employment was below that of 1892 and prices and profits were low. But electrical engineering was relatively active. In 1894 mechanical engineers, iron founders and machine tool makers were depressed. But the demand for electric lighting plant continued to be high. Much work was done by "those who having had experience as makers of steam engines, have added the manufacture of special electrical appliances."

The accepted way to develop a new line seems to have been to charge low prices until there were satisfied customers. And the elasticity of demand for electrical plant was low. In its 1893 article on price cutting the *Electrical Review* argued that the principal reason for price cutting was "advertisement". "There are many notorious examples of work done at a loss, simply to attract attention." It thought small firms were

1. The Reviews of the year.


mainly responsible for leading prices down."

"It is no uncommon occurrence to find in a list of tenders some three or four of the largest firms quoting within a few pounds of each other for large work and smaller firms offering to do the work for, perhaps two-thirds of the price at which more responsible firms would undertake it."

The recession reduced profits. But manufacturing firms were also handicapped by the structure of the capital market. As J.B. Jeffreys has shown the capital market was to a large extent geared to dealings in fixed interest securities. They were what lenders most wanted to purchase. But he has also pointed out that in the eighties and nineties there were considerable supplied of funds which bought ordinary shares in time of boom. However, in the case of the shares of electrical companies there is a difference between the eighties and nineties. In the boom of 1882 it was easy to raise money for electrical enterprises, in the boom 1888 - 91 much less easy. The speculation and over optimism of 1882 and the subsequent losses by shareholders made lenders very cautious concerning electrical enterprises. Matters had been made worse by the practice, common in 1882 - 3 of issuing partially paid shares and making calls when the company's output slumped. Electrical manufacturers had to borrow at least some of the money they required at fixed interest, even in the boom. Such was the case with Brush. At the end of 1888/beginning of 1889 some new shares were issued bringing in £4,640. In 1889 a call was made in partially paid shares making them all fully paid, and some more issued, raising £24,356. As late as 1892 £11,223 was raised by the issue of shares. But

in 1890 Brush issued £75,000 of new debentures. Yet even fixed interest
borrowing could be difficult. Crompton seemed to be particularly
unfortunate. In the end of 1889 and first part of 1890, £25,000 was
raised on 5½ debentures. But an attempt to sell another £25,000 of them
did not succeed. They were offered to the public in the summer of 1890;
by March 1891 only £10,800 of them had been sold. In the autumn of
1891 an attempt was made to sell £50,000 of preference shares. But they
did not sell very well and a year later the company tried to sell ordinary
shares to the value of £120,000. How well the ordinary shares sold we
do not know, but in February 1894 the directors asked for power to borrow
up to £100,000 in 4½ debentures. They were to pay off £50,000 of
existing debentures (presumably most of the second batch of 5½% had been
sold by then) and the loan from the bank which was £18,000. Although
by August 1894 the purchase of only £32,000 of these debentures had been
promised, by March 1895 £32,850 had been subscribed. This paid off the
bank loan and left some funds for working capital.

The speculative nature of ordinary shares, while it made it
difficult for some firms to raise money except at fixed interest, in other
cases encouraged financial manipulators. The E.C.C. suffered badly in
this way. The firm started with the desire to help the extension of
electric lighting not only by supplying machinery but by providing finance.
Some contracts were paid for partly in cash and partly in shares. Large
sums were spent on backing Lane-Fox in a patent suit against the Kensington
and Knightsbridge Electric Lighting Company. There was also considerable

1. On the parallel connection of incandescent lamps.
buying and selling of patents, licences and other speculative paper. Preference shares and debentures were issued to pay for alleged increases in business while as early as September 1892 the ordinary dividend was passed. Some of this activity was probably fraudulent. The Chairman of the E.C.C. was Jabez Balfour, who was also involved in the frauds that brought down the Liberator Building Society. In 1892 Balfour was exposed and fled to South America.

Borrowing difficulties pressed particularly hard on the electrical manufacturers because they were also substantial lenders to their customers. Plant was often paid for partly in shares. This partly reflects the difficulty electricity supply companies had in selling ordinary shares. In the 1890s these shares were of new companies and they yielded a very low return. Often no dividends were paid for the first few years. The municipalities, happily for the manufacturers, paid cash. But they usually did not pay promptly, keeping a large share of the payment until the equipment was erected and working. Brush claimed in 1894 that it had £50 - 60,000 tied up in this way.


3. The return on such assets was low even after the 1890s. Data is available for two companies. For the E.C.C. in the 19 years between 1896 and 1914, the percentage return was above 5½ for only two years - when undistributed profits invested in a reserve account are included - and for 9 years was below 3½. These shares however included E.P.S. shares. Few Brush figures are available for 9 years between 1901 and 1911. The rate of return was above 5½ for only two years, and below 3½ for five years.

The big increases in lending to consumers came during recession periods, when electricity supply companies could not easily sell shares, and when competition among the manufacturers was at its strongest. Lending increased much more rapidly than output. The best financial figures available relate to Brush, and are given in Table 65.

Falling prices seem to have squeezed profit margins from 1891 onwards. But as output was rising and capacity could be added at the margin quite cheaply total profits generally did not decline until after 1894. Nevertheless lending to customers reduced the rate of return. Brush is the only company for which we have good figures. They are given in Table 66 are probably fairly typical.

For a temporary recession profits were not very low when calculated in this way. But the return on issued capital was considerably smaller. In the case of Brush the return on issued capital plus loans seems to have been 6 - 7% in 1892 and as little as 2.5% in 1895. The difference between liabilities and assets was largely made up of the value of patents. The market for patents was very volatile and it is impossible to say much about their value. Nevertheless there can be little doubt that firms consistently overvalued their patents. They often simply paid too much for them.

The combined effect of falling prices, rising lending to customers, borrowing heavily on bonds, and past overcapitalisation of patents and goodwill would easily produce liquidity difficulties. As a large proportion of output was in a few large contracts profits could

1. See Table 74 for profits of Brush, Crompton & E.C.C. in the nineties calculated in a slightly different way.
Table 65.

Brush assets 1887 - 1895.

<table>
<thead>
<tr>
<th></th>
<th>(1) Fixed capital</th>
<th>(2) Stock &amp; work in progress</th>
<th>(3) Shares in other companies</th>
<th>(4) Net trade lending</th>
</tr>
</thead>
<tbody>
<tr>
<td>£</td>
<td>£</td>
<td>£</td>
<td>£</td>
<td>£</td>
</tr>
<tr>
<td>As at June</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1887</td>
<td>82,733</td>
<td>64,448</td>
<td>988</td>
<td>33,262</td>
</tr>
<tr>
<td>1890</td>
<td>134,701</td>
<td>84,468</td>
<td>11,534</td>
<td>16,638</td>
</tr>
<tr>
<td>91</td>
<td>128,551</td>
<td>78,326</td>
<td>15,092</td>
<td>32,734</td>
</tr>
<tr>
<td>92</td>
<td>138,044</td>
<td>77,391</td>
<td>39,399</td>
<td>27,491</td>
</tr>
<tr>
<td>93</td>
<td>147,949</td>
<td>91,556</td>
<td>42,732</td>
<td>70,455</td>
</tr>
<tr>
<td>94</td>
<td>151,660</td>
<td>114,681</td>
<td>42,915</td>
<td>86,367</td>
</tr>
<tr>
<td>95</td>
<td>154,148</td>
<td>100,829</td>
<td>61,237</td>
<td>96,543</td>
</tr>
</tbody>
</table>

1. For some years figures are estimated by interpolation.

2. Debtors minus creditors.

Source: Brush annual reports and statements at annual meetings.

The rapid rise in financial assets (3 & 4) stands out. Between 1890 and 1895 they increased by 46% while real assets (1 & 2) increased by 16%. The experience of the E.C.C. is similar. No figures are available before 1894. But between 1894 and 1896 the value of output rose by 30%, fixed capital rose by only £7,077 (2%) and stocks and works in progress by £15,026 (35%) while financial assets (net trade lending plus shares of other companies) rose by £37,053 (35%).
Table 66.

**Brush profits 1890 - 95.**

<table>
<thead>
<tr>
<th>Year ending</th>
<th>Profits £</th>
<th>% on items (1) &amp; (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>June 1890</td>
<td>20,029</td>
<td>9.1</td>
</tr>
<tr>
<td>1</td>
<td>23,854</td>
<td>11.5</td>
</tr>
<tr>
<td>2</td>
<td>35,661</td>
<td>16.6</td>
</tr>
<tr>
<td>3</td>
<td>34,395</td>
<td>14.4</td>
</tr>
<tr>
<td>4</td>
<td>35,231</td>
<td>13.3</td>
</tr>
<tr>
<td>5</td>
<td>15,394</td>
<td>6.0</td>
</tr>
</tbody>
</table>

Source: Brush annual reports and statements at meetings.

Accurate calculation of profits is not possible. The published figures are given net of debenture and other interest payments. It is only possible to make a crude adjustment for this.

Fluctuate suddenly. Sometimes penalties led to losses on big contracts which would hitherto have been profitable. Sometimes costs were badly underestimated. Brush ran into difficulties in 1895 because of a loss on the City of London contract. Generally Brush profits were fairly stable. On the other hand the profits of the dynamo department of Siemens show very considerable fluctuations.

Those liquidity difficulties seemed to have caused considerable tension between the engineers and business men in several of the large

1. i.e. men simply with commercial experience.
Table 67.

Siemens Bros. Profits on electrical machinery.

<table>
<thead>
<tr>
<th>Year</th>
<th>£</th>
</tr>
</thead>
<tbody>
<tr>
<td>1888</td>
<td>1,646</td>
</tr>
<tr>
<td>1889</td>
<td>-1,695</td>
</tr>
<tr>
<td>1890</td>
<td>17,823</td>
</tr>
<tr>
<td>1</td>
<td>1,226</td>
</tr>
<tr>
<td>2</td>
<td>629</td>
</tr>
<tr>
<td>3</td>
<td>-12,577</td>
</tr>
<tr>
<td>4</td>
<td>-4,155</td>
</tr>
<tr>
<td>5</td>
<td>9,824</td>
</tr>
</tbody>
</table>

Source: Siemens Bros. Historical Records.

From the early days business men had an important say in the policies of electrical firms. Control or partial control by business men was part of the price of becoming a joint stock company. Electrical manufacturing firms tended to be controlled by engineers only when they were small partnerships. Brush had always been controlled by business men. In 1888-9 Elwell-Parker became part of the E.C.C. and Crompton and Albright became Crompton & Company Ltd. In 1890 the Electrical Review collected figures of the occupations of company directors in established electrical companies. Only 20% of directors were engineers. The non engineers were often skilled in the market place - in buying and

1. 18% had titles, 9% were lawyers, 8% were military men and 45% were business and gentlemen.
But they had no basic understanding of the technical issues involved. They no doubt picked up a lot of technology, but they had not enough wide knowledge or deep understanding to be able to see the importance of new developments. They tended to be very excited about the prospects of new inventions in booms, and very cautious about them in recessions.

In two companies, the E.C.C. and Crompton, we know there were serious quarrels between the technical and commercial staff in the middle nineties. In the case of the E.C.C. it was complicated by the Balfour frauds. The financial position was such that the company had to be reconstructed in 1893. The management structure was altered. The board was almost completely changed. The old one had been large with sub committees. Co-ordination was bad and the main board was often ignorant of what was going on. Several of the senior officials were changed.

K. Garke, a commercial man who had helped in the re-organisation of Brush in 1893 was appointed managing director. The new administration soon however came into conflict with Parker, and in 1894 he, and three important heads of departments resigned, presumably not liking the way the re-organisation was taking place. The Board had no desire to retain Parker as Works Director yet wished to keep him as consulting engineer. This Parker declined and in April 1894 he left E.C.C. to set up a company of his own, T. Parker Ltd. The new E.C.C. board seems to have thought that extravagant experimentation was one of the causes of the troubles of 1890-3.

Within Crompton and Co. there was a quarrel for years between Crompton & Albright (the joint managing directors) and the commercial men. By the end of 1893 the Board had come to dislike the idea of two managing directors ostensibly because they felt their salaries were too high. The major disagreements seem to have been with Albright and in 1893 he left the company. But Crompton also had his differences - "even before the Boer War a certain amount of difficulty had arisen, and my relations with the firm had suffered". He was however to "continue to superintend the technical side". In practice Crompton took progressively less part in the affairs of the company and certainly had no major influence until after the first world war. F.R. Reeves the Secretary became the general manager.

Control thus passed decisively into the hands of the business men. The Chairman's speech explaining this is worth quoting for the light it shows on the dispute between the business and technical sides of the business.

"In the early days of the company there was a great deal of experimental work to be carried out ..... It required a great deal of application and attention on the part of those who were responsible for technical details and there is no doubt that, whilst the technical side of your business has been developed to the very highest state of efficiency the business side had got into a somewhat confused condition..... After considering all sides of the question it was decided that what was required was to define more completely the two departments, namely the technical side and the business side. I have already said, thanks to the work of your technical advisor, principally Mr. Crompton the technical side of the business is very good indeed. In order to provide for the business side, the Board resolved to appoint a general manager, who should not be a member of the Board, but open to every possible criticism and under the most complete control."

1. Letters from Viscount Emlyn (the Chairman) to Crompton 27 November 15 December 1893. Crompton Historical Records.
4. He was very much involved in founding the Electrical Engineering branch of the Royal Engineers. He served in the Board War. After it his main interest reverted to road transport.
There was something in what he said. Some technical developments had been pursued without careful consideration of possible profit and loss. R.K.B. Crompton had started an electric heating and cooking department in 1896, considering that they were going to be more important than electric power. This was a curious decision considering the very high cost of electricity. Yet what is significant in Emlyn's remarks was that he wanted to define more completely the two sides of the business, not to unite them. The commercial men had always felt that business matters should be kept away from the engineers; this was now to happen all the more.

Of the backwardness of British electrical machinery manufacture in the middle and late nineties there is no doubt. This is shown both in large and small matters. The two major developments of the early and middle nineties, electric traction and polyphase a.c. were neglected or ignored. In making smaller improvements like adopting multipolar rather than bi-polar dynamos they were also slow. Brush was slow to develop improvements. When it moved to Loughborough the company resolved to develop its own high speed engine. But it took a long time to do this, and it was not until 1896 that J.S. Raworth had developed the "Universal" engine to the stage where it could be placed on the market. This was too slow. From the late eighties on, the success of the Willans high speed engine must have made it clear that the rate of return from a similar engine was

1. See Chapter 5 PP 170 - 1.
2. See Chapter 6 PP 251 - 3.
3. Professor Guido Semenza writing in L'Elettricista. Quoted by R.H. Parsons, op.cit. P 165
high. Also the small high speed engine was obsolete for most power stations by 1900, because of big increases in the minimum efficient size of generator. How much financial stringency delayed the development of the Brush engine we do not know. But Raworth was an able engineer, and the Falcon works were equipped for building steam engines. Also there seems to have been no great interest in electric power. In 1893 Brush made an agreement with the Otis Elevator Company to make electric lifts, but the first Otis lift was not built until 1899. There was no other apparent interest in electric power—certainly it was not considered important enough to be mentioned in the quite full reports and Chairman's speeches.

I have argued that illiquidity was a major factor retarding development expenditure. The effect of the return and the structure of the capital market in causing this illiquidity apply to three of the major producers, Brush, the E.C.C. and Crompton. But Mather & Platt and Siemens had other business activities. Unfortunately we know little about Mather & Platt. However mechanical engineering was depressed in the early nineties and we may presume that they too suffered from liquidity problems. Siemens seems to have had the same trouble but for rather special reasons. In the early nineties it was still primarily a cable making firm. In the four years 1892-5 the value of the output of dynamos averaged £117,566 p.a. while that of cable averaged £407,038. In the late eighties

the cable business slumped, from an average of £624,641 p.a. in the six years 1880 - 85 to an average of only £271,059 in 1886 - 91. Hence dynamo manufacture could be expanded in the years 1883 - 91 without as big an increase in fixed capital as in the case of the other companies. Yet fixed plant continued to increase when the cable output grew again and electric wiring was installed in the works. No increase in financial assets appears in the accounts, but they were very heavily weighted with the cable business.

Table 68.

<table>
<thead>
<tr>
<th>Siemens Bros. Assets 1887 - 1895</th>
<th>Fixed Capital</th>
<th>Stock and work in progress</th>
<th>Shares in other companies and net trade lending</th>
</tr>
</thead>
<tbody>
<tr>
<td>1887</td>
<td>154,996</td>
<td>73,391</td>
<td>190,978</td>
</tr>
<tr>
<td>89</td>
<td>162.069</td>
<td>105,396</td>
<td>274,278</td>
</tr>
<tr>
<td>1891</td>
<td>155,473</td>
<td>85,292</td>
<td>175,768</td>
</tr>
<tr>
<td>93</td>
<td>189,337</td>
<td>211,195</td>
<td>- 4,133</td>
</tr>
<tr>
<td>95</td>
<td>207,569</td>
<td>143,069</td>
<td>181,541</td>
</tr>
</tbody>
</table>

Source: Siemens Bros. Historical Records.

Siemens Bros. in the nineties was closely controlled by Siemens and Halske in Berlin. When William was alive it was more independent. Von Loeffler who succeeded William tried to make London almost completely independent. A quarrel with the Siemens family in Berlin developed but Loeffler lost, resigned his managing directorship in 1888 and left the company altogether in 1890. Werner Siemens determined

1. For details of the dispute see J.D. Scott op.cit. PP 66 - 67.
that the new managing director should be one of the family and under close
control. Alexander Siemens, a third cousin to the brothers, who had been
in charge of electric lighting development since 1883 was chosen. He
was kept on a tight rein. Almost all matters of significance were fully
reported to Werner and Karl. Werner died in 1892 and Karl seems to have
treated Alexander very much as a junior branch manager. Short term capital
came largely from Siemens and Halske and the Deutsche Bank in Berlin.
This hampered Alexander even in his rather cautious policy. J.D. Scott
comments that the response from Berlin to his suggestions does not seem
to have been as warm as he might have hoped. Berlin seems to have been
responsible for technical developments. There were probably economies of
scale in this arrangement, but it would have hindered Siemens Bros. in so
far as close contact between the market and innovation was necessary for
innovations to be adopted.

1. Born 1847, educated in Germany. Worked in London in 1867. Returned
to Germany. Returned to England 1871 and worked as a pupil of
William’s mostly on regenerative furnaces. Died 1928.

2. J.D. Scott calls Alexander's policy an "ambitious, fighting policy". While I
have not had detailed access to internal material on this
point this view is not confirmed by the tone of Alexander Siemens’
public statements. See Chapter 6 for comments on electric power.
Chapter 8.

The Manufacturers of Electrical Machinery 1896 - 1914.

This chapter covers the great boom of the late nineties, the following recession and the boom just before the first World War. Table 69 gives an indication of output trends, although the boom of 1911 - 14 seems to be underestimated. Section I deals with the boom and period of new entry from 1896 - 1903. Section II deals with the difficulties of the recession 1904 - 10. In Section III the structure of the industry after the upheaval of 1896 - 1903 is discussed. Section IV discusses the 1911 - 14 boom. Sections I, II and IV contain tables showing the expansion of firms in the alternating periods of quickly and very slowly rising demand.

A new phase began in British electrical manufacturing in the late nineties. There was a major boom lasting from 1896 - 1903, a large number of new manufacturers, and the rise of important new firms who eclipsed the existing industry leaders. Two principal factors lie behind the change in the order of importance of firms; one was the very rapid rise in demand, and the reluctance of existing home manufacturers to expand; the other was the development of new products.

Up to the middle nineties electrical machinery was principally dynamos. The rise of electric traction from 1897 onwards was the main
Table 69.

Sales of Electrical Machinery

<table>
<thead>
<tr>
<th>Sales to utilities</th>
<th>Other home sales</th>
<th>Total home sales</th>
<th>Export balance (exports - imports)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>£000</td>
<td>£000</td>
<td>£000</td>
</tr>
<tr>
<td>1896</td>
<td>647</td>
<td></td>
<td></td>
</tr>
<tr>
<td>97</td>
<td>840</td>
<td></td>
<td></td>
</tr>
<tr>
<td>98</td>
<td>1,210</td>
<td>107</td>
<td>1,317</td>
</tr>
<tr>
<td>99</td>
<td>1,799</td>
<td>140</td>
<td>1,939</td>
</tr>
<tr>
<td>1900</td>
<td>2,740</td>
<td>235</td>
<td>2,975</td>
</tr>
<tr>
<td>01</td>
<td>2,705</td>
<td>211</td>
<td>2,916</td>
</tr>
<tr>
<td>02</td>
<td>3,100</td>
<td>350</td>
<td>3,450</td>
</tr>
<tr>
<td>03</td>
<td>3,329</td>
<td>720</td>
<td>4,049</td>
</tr>
<tr>
<td>04</td>
<td>2,827</td>
<td>846</td>
<td>3,673</td>
</tr>
<tr>
<td>05</td>
<td>2,347</td>
<td>1,024</td>
<td>3,371</td>
</tr>
<tr>
<td>06</td>
<td>2,061</td>
<td>1,311</td>
<td>3,372</td>
</tr>
<tr>
<td>07</td>
<td>1,378</td>
<td>2,737</td>
<td>4,115</td>
</tr>
<tr>
<td>08</td>
<td>1,162</td>
<td>1,002</td>
<td>2,164</td>
</tr>
<tr>
<td>09</td>
<td>966</td>
<td>2,305</td>
<td>3,271</td>
</tr>
<tr>
<td>1910</td>
<td>978</td>
<td>1,429</td>
<td>2,407</td>
</tr>
<tr>
<td>11</td>
<td>932</td>
<td>1,092</td>
<td>2,024</td>
</tr>
<tr>
<td>12</td>
<td>827</td>
<td>1,440</td>
<td>2,267</td>
</tr>
<tr>
<td>13</td>
<td>1,276</td>
<td>1,316</td>
<td>2,592</td>
</tr>
</tbody>
</table>

1. Electricity supply, electric tramways and the London Underground.

For method of calculation see Appendix P 504.
factor that changed this. The traction motor of the late eighties was a modification of a dynamo. However the traction boom in the United States 1890 led to the development of a specialist traction motor, complete with special control equipment. Between 1889 and 1895 there was very rapid progress in design. The operating efficiency of traction motors rose; their weight per horse power fell; their electrical design was improved to make waterproofing them possible; gearing was improved to reduce noise and maintenance. At the same time when demand was high American manufacturers were able to build large numbers of traction motors at low unit costs. Motor prices fell dramatically; from £4,500 for a two motor equipment in 1889 to £2,600 in 1891 and still further to £750 in 1895. All prices at this time were falling rapidly but H.C. Passer attributes 35% of the fall in motor prices from 1891 to 1895 to improvements peculiar to motors - that is in addition to the improvements which reduced the price of railway generators. In these very years 1891 - 95 English electrical manufacturers ignored traction motors, for which there was no demand.

As well as introducing specialist traction motors and control equipment, the rise of electric traction stimulated further changes in generators. Traction put much heavier strains on generators than did lighting, and traction generators had to be more robust. Also, both because the amount of power used by a tramway in the average town was much greater than that used for electric lighting, and because

2. Railway generators may be taken as typical of all rotating plant except traction motors. If there is any bias in using their prices as estimators it lies in overstatement of the average price fall.

the change in the load throughout the day was less, it became better to use bigger generators. This reinforced the move towards bigger generators for lighting stations, which was taking place at the same time. This was a limited movement, as most of the plant installed in British Central Stations in the late nineties was still quite small. But nevertheless it caught home manufacturers on the wrong foot, for two reasons. Firstly because they were committed to building small generators for high speed engines, and the size of high speed engines could not easily be increased. The larger, slow speed generators made by German and American firms were of a different design and required different productive resources to manufacture them. They were physically much larger pieces of machinery. When in 1899 the E.C.C. decided to begin making slow speed generators they had to put up a new shop equipped with two special extra-large drilling machines. Secondly these large generators were partly becoming more advantageous because they generated polyphase a.c. For traction, d.c. motors were much better than a.c. ones. But a.c. offered much cheaper transmission at high voltages. Thus in the middle nineties American engineers developed a system of high voltage polyphase a.c. transmission and conversion to d.c. for feeding sections of the tramway or railway. Single phase a.c. was not suitable for the converting plant. Lighting was often on a d.c. distribution network.

A cheap way to increase capacity by the late nineties was to build new polyphase a.c. central stations, transmit at high voltages and

1. Chapter 3.
3. The 4000 KW flywheel alternators at Manchester's Stuart Street station weighed 112 tons each.
convert to d.c. to feed the distribution network.

The movement towards bigger generators was also stimulated by the development of the Parsons steam turbine. The turbine had great advantages over other generators in large sizes and after 1903 superseded the large slow speed generating set. Dynamos for turbines were rather different from generators for either high or low speed reciprocating engines. They were subject to particular mechanical strains because of their very high speed of rotation. The stresses were particularly bad with big plant. For example quite considerable difficulties were experienced when the first 350 kW turbo-alternators running at 3000 r.p.m. were installed. There were teething troubles, particularly with the alternators, which went on for about eighteen months, although after that the sets worked well. The development of the high speed alternator is as much Parsons’s achievement as is the steam turbine. Nearly all improvements are due to him, and until after 1901–03 no other British electrical engineers showed any interest.

4. There were either motor generators or rotary converters. The former was an a.c. motor on the same shaft as a d.c. generator, the latter a machine with an armature wound for both a.c. and d.c., with a.c. slip rings on one end of the shaft and a d.c. commutator on the other. Rotary converters were cheaper, although they needed a narrower frequency range.

1. Chapter 3.

The advent of factory power introduced a rather new and more specialist product - factory motors. Before the late nineties most electric motors were little different from dynamos. This was because very little electric power was used. But with the advent of three phase a.c. and the big reduction in motor prices 1901 - 05 many more motors were used, and attention was given to particular design problems, and to particular manufacturing methods. During the years 1901 - 05 specialist machinery was put down in English electrical machinery factories for making industrial motors. But there was no divorce between motors and other plant. Large motors - more than 50 - 100 h.p. were little different in particular technique from small generators and rotating converting plant.

The emergence of these new sub divisions of electrical machinery, traction equipments, large generators and factory motors led to considerable entry into electrical manufacture. Traction equipment alone attracted three very large firms, all bigger than existing home manufacturers. Two, British Thomson-Houston, and British Westinghouse were offshoots of existing American manufacturers of electrical machinery. The third, Dick, Kerr & Co. was an established mechanical engineering firm specialising in road transport with considerable experience in building equipment for cable and steam tramways. B.T-H and British Westinghouse did not begin manufacturing in Britain until 1902, but before that large quantities of equipment built


at Schenectady and Pittsburg were installed in Britain. B.T.H. was one of the prime movers behind the beginnings of electric traction. At first B.T.H. was a sales agency for American equipment. Although the capital was largely in German and French, as well as American hands, the engineers were Americans. General Electric provided two of its best traction engineers, H.P. Parshall and H.M. Hobart. All the plant except meters came from General Electric.


3. Born 1865. Lilford, New York. Educated at Cornell & Lehigh Universities. Worked with Sprague Electric Railway and Motor Co. (Sprague was one of the most important traction pioneers) He became chief engineer of the Wiensstrau Dynamco & Motor Co. in Baltimore where he developed the 4 pole slow speed railway motor. He then became chief designing engineer of Edison General Electric and stayed on as such when General Electric was formed.


A very large amount of the traction motor equipment used in Britain in the early days of electric traction was American. As the early electric tramway and railway contracts were usually for all the electrical equipment, the statistics of the makers of generators give a good picture of the general situation in the absence of other figures. At the beginning of 1893 the *Electrical Trades Directory* gave details of 3840 KW of generators in traction power houses. 2830 KW was distinguished by maker; 35% of this was made by General Electric and Westinghouse. Generators totalling 11,420 KW were in the course of manufacture or erection in new traction power houses. 10,860 KW was distinguished by maker; General Electric was supplying 9,000 KW and Westinghouse 1,200 KW. Figures of motors supplied are unsatisfactory but there is no doubt that in the years 1897 - 1900 the General Electric motor supplied through B.T-H. was not only used more than any other make of motor, but probably more than all other motors put together.

B.T-H. were so successful that it is not surprising that they were soon looking for manufacturing facilities. A union with Siemens Bros. was proposed which would provide B.T-H. with a factory, reduce competition and pool engineering experience. But the Siemens Directors in Berlin delayed and the idea lapsed. General Electric then bought a controlling

1. Siemens & Halske were strong in traction equipment and Siemens Bros. was perhaps the strongest potential competitor in England. They were building the electrical equipment for the Waterloo and City railway at the time.

2. J.D. Scott. *op.cit.* PP 70 - 1.
share in B.T-H, a factory was built at Rugby during 1900 and 1901 and manufac-
turing began in March 1902. All the important staff of the new factory
came from General Electric's own organisation.

Westinghouse had also had a sales company in Britain for some
time. In 1897 an important contract was obtained for three 1500 kW
two phase alternators for the Willesden central station. When electric
traction began to develop in Britain, George Westinghouse became impressed
with the size of the potential market. He particularly noticed the
density of traffic on British railways. In the summer of 1899 he bought
land at Trafford Park, Manchester and founded the British Westinghouse
Electric and Manufacturing Co. Until manufacturing began at the end of
1902, Westinghouse plant which was installed in this country in considerable
quantities was built at Pittsburg. The key posts in the new works were
filled by Americans. Americans were also placed in less important posts
and Westinghouse even brought eighteen foremen from Pittsburg. He also
enlisted a number of Englishmen, mainly from technical institutions and
sent them to Pittsburg for two years training, preparatory to their
occupying the lesser posts at Manchester. Later they would fill the


2. They were the Managing Director, the Managing Engineer, the Traction
Engineer, the Works Manager, the Assistant Works Manager, the Manager
of the Rugby Lamp Works and the General Commercial Manager.
(B.T-H. Reminiscences P 17).

3. The first English Westinghouse Company was founded in 1899, no doubt
in connection with the supply of generating plant to the Sardinia Street
Station of the Metropolitan Electric Supply Co.


important posts when the Americans went home.

General Electric and Westinghouse saw the prospects of new markets in Britain, but they were also driven to look for new outlets by the deep American recession of the middle nineties. In the United States the demand for electrical machinery increased rapidly during the eighties with the success of electric lighting. The success of the early electric trolley in the late eighties increased demand still further. Then in 1892-3 the boom broke and the subsequent recession was long and severe. Not until 1899 did the sales of General Electric overtake those of 1893. In the circumstances it is almost certain that there was excess capacity until the late nineties. The Westinghouse position was doubtless similar. Electric traction did not develop as quickly in Europe as in the U.S. and it was natural that General Electric, owning the very strong Thomson-Houston and Sprague patents should seek to open up the European electric traction market. They did this in Germany slightly earlier than in England.

In 1897 Dick, Kerr and Co. bought a factory in Preston to manufacture electric tram bodies. In 1899-1900 these works were considerably extended so that the firm could manufacture electric traction motor equipments and power station plant. Although management and finance were British, the technical director was an American, S.H. Short. The electrical machinery works were planned in consultation with Short, using

1. H.O. Passav, op. cit. P

2. The tramcar works were begun as the Electric Railway and Tramway Carriage Works, and later became the United Electric Car Co. The electrical machinery works were registered in 1893 as the English Electric Manufacturing Co., but were absorbed by Dick, Kerr in 1903.

3. over ...
American machinery was to be built under his patents.

Although these three firms were attracted by the traction plant market, they were all producers of all electrical machinery. They were ready and able to build polyphase equipment, large generators, and small factory motors as well as smaller dynamo transformers converters etc. But there were also more specialist entrants. Two firms entered because of the possibilities of bigger generators—Ferranti and Parsons. Strictly speaking neither was a new entrant for Ferranti had been making electrical machinery since 1882 and Parsons from 1889 (1884 when a partner with Clarke Chapman), but in the boom period 1896-1903 they both became new large producers. There was considerable similarity between them, they were both founded and controlled by great inventors, business men were important in neither. The major difference is that Ferranti failed while Parsons succeeded.

J. Born 1858, Columbus, Ohio. Educated Ohio State University. In 1876 he became Assistant Professor of Physics at Denver University. He worked on railway motors and in 1885 resigned his Professorship to concentrate on electric railway work. In 1889 he moved to Cleveland, Ohio and formed the Short Electric Railway Co. (Brush was a large shareholder) to manufacture railway machinery. In 1893 he became connected with the Walker Manufacturing Co. of Cleveland. The Walker Co. entered electric traction and was so successful that it was bought up in 1893 by financial interests controlling the Westinghouse Co. In 1893 Short came to England to complete the arrangements with Dick, Kerr. He intended to return soon to the U.S. but died in 1902 of appendicitis. (E.R. Vol. 51 P 747 31 October 1902)

Ferranti was the one English electrical manufacturer who built dynamos for direct coupling to slow speed engines in the middle nineties. After he left Doford Ferranti concentrated on building slow speed alternators. He got several contracts including a 1000 KW alternator for the London Electric Supply Corporation in 1893 and two 1500 KW alternators in 1895. In 1895 he decided to begin the manufacture of steam engines, and thus produce the whole generating set. Thus he bought a larger works at Hollinwood, in 1896. This was a good time to begin the manufacture of large steam alternators. The market for electrical plant was expanding rapidly, and one would have expected the future of large slow speed generators to be good. But the firm did not succeed. In 1903 it went into the hands of the Receiver and the manufacture of steam dynamos ceased.

The principal reasons for this failure seem to be in the personality of Ferranti himself. There is no doubt that he was an engineer of genius; there is equally no doubt that he did not have much commercial sense. As early as 1883, Ince, his financial backer, had expressed unease at Ferranti's habit of endlessly improving machines while making them. He complained that there was a growing number in a semi-completed state while very few had been finished. At Hollinwood the situation was similar. Engines were produced incorporating first rate engineering design, and each with its own innovation. But delivery

1. Between Manchester and Oldham.
2. And also his father-in-law.
3. Letter from Ince to Ferranti, 13 April 1883. Ferranti files, Hollinwood.
was nearly always very late. Penalties for late delivery were usually heavy. F. Bailey tells of many examples of late delivery and the consequent financial losses.

"(At Dankside) he accepted an order for two steam alternators of 1500 Kw each, and once more improved on everything he had done before, but, unfortunately there was an alarming delay in delivery. The first engine, promised for the end of 1896 was not at work until 1898 .... The second machine was finished in 1899 .... These engines were full of novel and ingenious improvements; ....... At Pajåley delivery was two years late under a penalty of £5 per day .... At Worcester the delay was three years before a satisfactory test could be made."

Also it is very surprising that Ferranti seems not to have concerned himself with polyphase a.c. All his alternators were single phase. By the late nineties it must have been clear that large polyphase alternators had additional advantages, and one of Ferranti's missions since 1887 had been to persuade supply authorities of the advantage of large scale generating plant. In mitigation, however, one must remember that the average supply undertaking was not interested in polyphase a.c. and the American engineers engaged in designing traction seem to have preferred well tried American machinery.

Parsons by contrast was very successful. By 1904, as Table 80 shows, 22% of the generators installed in British Central Stations were built by that firm. This was a peak; later, other turbine manufacturers reduced the Parsons share. English central stations were slow to adopt

1. Ferranti was able to escape this penalty in the end.

the turbine, but this was partly because the development of the turbine was slow. The master turbine patent was taken out in 1884 when Parsons was a junior partner with Clarke, Chapman and Co. In 1889 he quarrelled with Clarke, Chapman and left them to found a firm of his own. But in doing so he lost his patents, and obliged to try and build steam turbines which did not infringe his own patents. Despite the use of an inferior method of design he achieved good results and succeeded in getting turbo-alternators installed in several central stations. In 1894 he purchased his patents from Clarke, Chapman but by the end of 1895 had already decided to develop the steam turbine for ship propulsion. This diverted his prime interest from land turbines until the end of the century. Parsons was also short of money. Finance was provided privately, much of it it seems from his eldest brother. Not until 1913 did his firm become even a private company.

Parsons made only turbo electric generating machinery.

Another entrant with a limited range of electrical machinery was G.E.C. Originally a firm of electrical apparatus wholesalers, it began to make small electrical apparatus in 1889. Then in 1897 H. Hirst realised that the polyphase a.c. motor was an important development and its use might lead to extensive factory electrification. Thus he bought a licence.

3. From 1889 to 1894 he built turbines in which the steam flowed radially rather than axially.
5. The firm also made condensers. Marine turbines were made at the Parsons Marine Turbine Works at Wallsend.
6. The General Electric Company. Referred to as G.E.C. to distinguish it from the American General Electric with which...
to manufacture induction motors. In the summer of 1900 with the demand for heavy plant much in excess of the supply C.E.G. decided to construct a works for building electrical machinery at Hillmorton, Birmingham. This was for large plant, chiefly generators, and large motors, where the firm could also take advantage of its polyphase knowledge. By 1903 the factory was at work. In the earliest days very large generators were not made.

The rise of the growing in demand 1896 - 1900 also attracted new firms who had no particular advantage, and who were not anxious to exploit any particular segment of the machinery market. In 1899 the firm of D. Barco Peebles, having very recently started the manufacture of motors and generators, had so much work on hand that it decided to erect a large new works at Edinburgh. In the same year the Lancashire Dynamo and Motor Company built a works next to Westinghouse at Trafford Park. At the time the British Electric Transformer Co. started, concentrating on the manufacture of static transformers.

The home manufacturers of the middle nineties expanded little in the boom. They were illiquid, they had been through a lean time of rising output and falling prices, they had seen the optimistic expectations of 1892 and 1893 - 95 fade rapidly. Control had passed into the hands of cautious men. On top of this the size of the rise in demand for electrical

7. Born 1863. He was educated at the Commercial Industrial Schools and the Polytechnikum of Munich. 1882 joined E.P.S.


1. An induction motor is the engineering term for a polyphase a.c. motor
### Table 70.
The Expansion of Assets, 1896 - 1904.

<table>
<thead>
<tr>
<th>Company and Date</th>
<th>Increase in fixed assets after depreciation £</th>
<th>Increase in stocks &amp; work in progress £</th>
<th>Increase in financial assets £</th>
</tr>
</thead>
<tbody>
<tr>
<td>British Westinghouse (to July 1904)</td>
<td>2,008,321</td>
<td>1,149,493</td>
<td>157,841</td>
</tr>
<tr>
<td>E.T.H. (to June 1904)</td>
<td>427,635</td>
<td>266,233</td>
<td>714,451</td>
</tr>
<tr>
<td>Dick, Kerr &amp; Elect. Rly &amp; Carriage Co. (to June 1904)</td>
<td>710,050</td>
<td>191,880</td>
<td>278,479</td>
</tr>
<tr>
<td>Siemens Bros. Dynamo Works (to Dec. 1904)</td>
<td>276,767</td>
<td>121,839</td>
<td></td>
</tr>
<tr>
<td>Brush (June 1896 - Dec. 1903)</td>
<td>202,975</td>
<td>145,818</td>
<td>108,592</td>
</tr>
<tr>
<td>Bruce, Peebles &amp; Co. (to Dec. 1903)</td>
<td>93,695</td>
<td>56,494</td>
<td>29,512</td>
</tr>
<tr>
<td>Crompton (March 1904)</td>
<td>55,819</td>
<td>86,357</td>
<td>40,811</td>
</tr>
<tr>
<td>E.C.C. (June 1896 - May 1904)</td>
<td>35,928</td>
<td>-6,335</td>
<td>-8,645</td>
</tr>
<tr>
<td>Parker (to April 1904)</td>
<td>25,801</td>
<td>28,856</td>
<td>23,551</td>
</tr>
<tr>
<td>G.E.C. (Witton) (to Dec. 1906)</td>
<td>214,913</td>
<td>58,352</td>
<td></td>
</tr>
<tr>
<td>British Electric Transformer (to Dec. 1904)</td>
<td>19,313</td>
<td>21,141</td>
<td>18,294</td>
</tr>
</tbody>
</table>

1. Lending from the parent firm has been deducted in the accounts. This is likely to have been £100 - 200,000. Also the parent lent heavily to customers through Traction and Power Securities Ltd.

2. Work in progress is included under "debtors".

3. Includes goodwill.

4. As Siemens & G.E.C. were involved in business other than the manufacture of electrical machinery firm data is not relevant. 5. Earlier figures
### Table 7.1.
The Source of Funds 1896 - 1904.

<table>
<thead>
<tr>
<th>Source</th>
<th>Borrowing on ordinary shares</th>
<th>Borrowing on Preference shares</th>
<th>Borrowing on Debentures</th>
<th>Retained profit before depreciation</th>
</tr>
</thead>
<tbody>
<tr>
<td>British Westinghouse</td>
<td>£750,000</td>
<td>£2,500,000</td>
<td>£616,353</td>
<td>£200,750</td>
</tr>
<tr>
<td>(to July 1904)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B.T.H.</td>
<td>£200,000</td>
<td>£395,690</td>
<td>£212,000</td>
<td>£515,178</td>
</tr>
<tr>
<td>(to March 1904)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dick, Kerr &amp; Elect.</td>
<td>£170,000</td>
<td>£200,000</td>
<td>£273,642</td>
<td>N/A</td>
</tr>
<tr>
<td>Rly. &amp; Carriage Co.</td>
<td>(to June 1904)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brush</td>
<td>(June 1896 - Dec 1903)</td>
<td>£31,009</td>
<td>£31,009</td>
<td>£75,000</td>
</tr>
<tr>
<td>Crompton</td>
<td>(March 1896 - 1904)</td>
<td>£159,050</td>
<td></td>
<td>£100,000</td>
</tr>
<tr>
<td>E.C.C.</td>
<td>(June 1896 - May 1904)</td>
<td>£4,200</td>
<td>£30,094</td>
<td>£77,870</td>
</tr>
<tr>
<td>Parker</td>
<td>(to April 1904)</td>
<td>£23,636</td>
<td></td>
<td>£20,700</td>
</tr>
</tbody>
</table>

The figures in this table are only very crude. New shares are shown as being sold at par, except where there is evidence to the contrary. But it is likely that they often were not sold at par. These structures also apply to Tables and it is only possible to collect these figures for some companies. Sometimes reconstructions have meant one has to eliminate firms, sometimes, as for example with Siemens, the balance sheet information is utterly inadequate.

Source: Company Balance Sheets.

* 78 and 87.
machinery in the late nineties was quite unexpected. Brush and Siemens were the only ones to expand substantially.

The Brush expansion was chiefly in the traction department, and was more in rolling stock than in motor equipment. Capacity was first extended in March 1898, and further extensions were made to the car shops in 1899. But not until 1900 was a plant laid down for making trucks. After 1900 Brush often made bodies to be powered by another manufacturer's motors. Expansion followed the rise in demand. From the end of 1896 Brush began to work in association with British Electric Traction. This association became progressively closer until by 1906 (or possibly earlier) B.E.T. controlled the majority of Brush shares. Other Brush departments were neglected. They showed no enthusiasm for large generator work or factory electrification.

Siemens like other home firms seems not to have been anxious to expand rapidly. But by 1899 Berlin was dissatisfied with the slow progress of the London firm. They wanted a large heavy plant works in England similar to those of Siemens and Halske at Charlottenburg. Eventually land was purchased at Stafford and a factory built. In 1903

1. Chapter 1. PP 92 - 3.
2. Mather & Platt built a new works at this time. Unfortunately we do not know how much the electrical department expanded.
3. The truck consists of wheels and motors. The very early electric trams were built on the horse car principle, motors being fitted to a body which was built to be pulled. This was not very satisfactory and was changed to the truck principle - bodies being mounted either in two sets of tractor bodies or on a four wheeled truck; the advantage of the latter design was that the motors were an integral part with the wheels - the unit thus being stronger and less likely to be damaged by running.
4. J.D. Scott, op.cit. P 74.
the dynamo department was moved there from Woolwich.

The failure of four of the five main producers of the early and middle nineties to develop the new very large generating plant, meant that they were slowly squeezed out of the central station generator market. Mather and Platt shifted quickly to building plant for factory electrification. In 1898 they built their first induction motors, and their deliveries of central station generators fell off very sharply after 1901. Parker, when taken over by Rees Roturbo in 1906, also gave up central station generators. Brush concentrated on traction and never built very large generating plant. Crompton too never built very large plant, but continued to build central station plant for electricity supply station in small towns where there was insufficient demand for big plant. The E.C.C. having installed special plant for large generators in 1899 continued to build some. But they were not important in this field nor was it of major importance to E.C.C. after 1900. They do not seem to have made generators for steam turbine driven units.

1. 75 years of Electrical Engineering. A brief history of the Mather and Platt Electrical Department.

2. Crompton had a special arrangement with the Electricity Supply Corporation. Late in 1902 Crompton helped to form the E.S. Corp. It took over the Chelmsford station and several provisional orders from Crompton. Supply was begun in Dalkoith, Dollar, Jedburgh and Melrose in 1904, in Exmouth in 1905, in Dumbarton and Falmouth in 1906, and in Totnes in 1911. Crompton was to act as contractors for the Corporation at prime cost plus 15%. In May 1905 this was modified to prime cost plus 10%. These were all small control stations - by December 1906 the E.S. Corp. had spent only £272,024 on capital account (excluding Chelmsford). Only a small proportion was on electrical equipment (Based on the Minute Book of the E.S. Corp. Among the Central Electricity Generating Board Historical Records at Great Portland Street
The demand for electrical machinery rose very rapidly from 1896 to 1903; after 1903 it rose much more slowly up to 1910. But as Table 72 shows there was no marked recession in either the value or volume of output. But there was a considerable fall both in prices and profit margins from 1900-01 onwards. There are two reasons, the collapse of the German boom in electrical equipment in 1900, and the fact that by 1903-04 there

Table 72.

British Production of Electrical Machinery 1903-1913.

<table>
<thead>
<tr>
<th>Year</th>
<th>Current prices £000</th>
<th>1907 prices £000</th>
</tr>
</thead>
<tbody>
<tr>
<td>1903</td>
<td>3,967</td>
<td>2,387</td>
</tr>
<tr>
<td>1904</td>
<td>3,711</td>
<td>2,353</td>
</tr>
<tr>
<td>05</td>
<td>3,556</td>
<td>3,026</td>
</tr>
<tr>
<td>06</td>
<td>3,676</td>
<td>3,818</td>
</tr>
<tr>
<td>07</td>
<td>4,541</td>
<td>4,515</td>
</tr>
<tr>
<td>08</td>
<td>2,972</td>
<td>3,213</td>
</tr>
<tr>
<td>09</td>
<td>4,209</td>
<td>3,967</td>
</tr>
<tr>
<td>1910</td>
<td>3,487</td>
<td>4,332</td>
</tr>
<tr>
<td>11</td>
<td>2,824</td>
<td>6,248</td>
</tr>
<tr>
<td>12</td>
<td>3,153</td>
<td>7,265</td>
</tr>
<tr>
<td>13</td>
<td>3,615</td>
<td>8,743</td>
</tr>
</tbody>
</table>

Source: As Table 69.
had been so much entry into electrical manufacturing that there was overcapacity at home.

The traction and central station boom in Germany had begun earlier than in Britain, and finished earlier. In 1901 there was a sharp recession in the demand for electrical plant, and this led to a sharp rise in the propensity to export to Britain. As a result prices fell sharply. In the years 1901-04 there are many instances of German firms tendering particularly low prices. The tenders for the L.C.C. tramway generators in 1901, given in Table 73 provide a good example. The Continental tenders were particularly low for the three phase a.c. generators. Other examples could be given for small and medium size as well as large contracts.

The slow growth of demand after 1903 made the overcapacity of 1903-4 difficult to digest. Prices continued to fall and profits declined to a low level. This overcapacity was largely concentrated in three firms, British Westinghouse, Siemens and G.E.C. The first two tried hard to achieve full capacity working and were responsible for driving down prices. All three made lower profits than other manufacturers.

British Westinghouse's factory was much too big for its needs. Also it had been built in great haste and was consequently expensive. The shops were lavishly equipped with expensive American machinery. It is likely that highly capital intensive methods of production were used, which were not well adapted for English wage rates. The rate of growth

2. See Chapters 3, 4, 5 and 6.
3. J. Dummelow, op. cit. PP 4 - 7.
Table 73.

Tenders for generators for the L.C.C. tramways 1901.

Average of lowest tenders.

d.c. plant 3 phase a.c. plant.

<table>
<thead>
<tr>
<th></th>
<th>£</th>
<th>£</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continental Firms</td>
<td>28,160</td>
<td>42,029</td>
</tr>
<tr>
<td>American Firms</td>
<td>29,763</td>
<td>50,243</td>
</tr>
<tr>
<td>British Firms</td>
<td>29,498</td>
<td>51,493</td>
</tr>
</tbody>
</table>

1. A.E.G., Schuckert, Helios, Lahnweter and Witting (Germany)
   Brown-Boveri (Switzerland) International Electrical Engineering (Belgium)

2. British Westinghouse, B.T.H. and Bergtheil and Young (Bullock Mfg. Co.)

3. British Westinghouse and B.T.H.

   Parsons, Siemens.

   Parsons, Siemens.

NB For the d.c. plant the Brown-Boveri tender was very high.
If excluded, the Continental average is £26,820.
For the d.c. plant 29 firms sent in 212 tenders.
For the a.c. plant 22 firms sent in 160 tenders.


of demand was substantially over-estimated. In December 1905, the company
stated that financial results would get better when the long awaited
traction boom came. But by then the traction boom was over.

There also seems to have been poor management. Labour relations
were bad when the work required a high proportion of skilled men. This was

partly because of the rather unthinking use of American practice. Relatively more priority was given to increasing output than to financial discipline; "on top of the very heavy initial outlay there had been too lavish expenditure in many directions" Orders were late on completion and unprofitable when completed owing to optimistic tendering.

By 1905 the situation had become so bad that the top management was changed. In November George Westinghouse sent his immediate assistant, Newcomb Carlton to Manchester, and he soon became sole managing director. Philip A. Lange, manager of all the American Company's works in East and Pittsburg, Allegheny, Cleveland, Newark was sent to assist Carlton by making a six months review of the situation. But he stayed and in July 1906 was appointed general manager of the works. Major reforms followed and matters soon began to improve.

Siemens' difficulties at Stafford stemmed initially from having been too slow in extending their heavy plant business. The new works were not fully ready until 1904. The Siemens share of the heavy plant market had fallen and this was difficult to regain. In 1904 the Stafford works were only partly occupied and business was again unsatisfactory.

1. J. Dummelow, op. cit. PP 27 - 8. For example, The Pittsburg practice of works police patrolling the shops to see that everyone was hard at work was used. The American foremen were hard task masters. Labour was engaged and discharged indiscriminately, and dismissal slips were constantly expected in pay packets.

2. ibid., P 29

3. ibid., P 33 - 5. The accounting system was changed. Separate trading departments were formed with their own accounts. An attempt was made to improve industrial relations. The design of machinery was changed to allow for the lower cost of labour relative to material in Britain compared with the U.S.
in 1905. Losses were heavy, and as with Westinghouse the management was not beyond reproach. Carl Friedrich Siemens was in charge of the new works at first. When he was replaced by Carl Kottgen, the latter complained of past mismanagement.

These difficulties led to the transfer of the Stafford works from Siemens Bros. to Siemens-Schuckertwerke in Germany. In 1906 the Stafford works were registered as Siemens Bros. Dynamo Works Ltd, and leased to Siemens-Schuckertwerke for ten years. This arrangement did not, however stop the losses, for the Stafford works continued to be the least profitable of British electrical machinery factories. In the decade 1906-16 the accumulated losses shown in the books were over £700,000; adding interest on money lent at 5%, the figure came to around £1 million.

The Witton works of G.E.C. were not in full working order until 1904, and they seem to have been working well under capacity for some years; indeed it is unlikely, judging by turnover and fixed plant figures that they were fully occupied until after 1910. This, despite the fact that their early entry into the manufacture of polyphase a.c. equipment should have put them in a good position to sell plant for factory electrification. Witton lost money. Most of these losses were

2. Born 1872. The son of Werner Siemens by his second wife. He had worked with Jay Gould in the United States.
3. Soon after 1906
4. J.D. Scott, op.cit. PP 75 - 6.
5. In 1903 Siemens and Halske and Schuckert and Co. amalgamated their heavy engineering departments.
6. J.D. Scott, op.cit. P 87
due to the carbon works, which were adjacent to the engineering works. Carbon works losses averaged £10,000 p.a. on a turnover of £20,000 - £30,000 p.a. But as Table 74 shows engineering also did badly.

The other companies did not do as badly, as is shown in Table 74. This was partly because they did not have the special difficulties of Westinghouse and Siemens. Also the machinery market was to some extent segmented. Those firms concentrating on traction and industrial electrification did rather better than those concentrating on central station work. The demand for trams was kept up reasonably well until after 1907, as is shown in Table 75. This partly accounts for the profitability of Dick, Kerr. Profits did not fall until the year ending June 1903; before then they gave a good return on assets. Profits in car bodies seem to have been rather better than profits in electrical machinery manufacture. Dick, Kerr seems to have increased its share of the declining tramcar market. Brush's profits also did not fall until after 1907, although their profitability was less than that of Dick, Kerr, probably simply because they were less efficient. Brush's volume of output seems to have been rising up to and including 1907, when output was said to be a record for the firm. Then 1908 was reported to be a year of exceptional depression. B.T.H. similarly suffered a severe drop in

1. The profits of the car body subsidiary were as good as those of the main firm. The main firm's results include contracting which was considerably more profitable than manufacturing. J. & G. White, the electrical contractors made high profits during the years 1905 - 09. The average return on assets was 14.9% p.a. (Unweighted average of annual rate Feb. 04 - Feb. 10)


The works were burnt down in 1896.

See notes on P. 380a.
Notes to Table

Statistics are not available for other manufacturers of heavy electrical plant. Siemens manufactured plant and cables. Their profits are given under the cable makers. Siemens Brothers Dynamo Works which made heavy machinery for Siemens, from 1903, made profits which seem to have been either zero or negative for 1907 - 1913.

Profits are taken before the payment of debenture and other interest and after depreciation. As interest payments are often not shown in the published figures provided by the company estimates have often had to be made. They can only be based on loans and debentures as shown in balance sheets and are thus crude. The situation is particularly bad in the 1890s. For B.T.H. who borrowed heavily from General Electric considerable estimating has been necessary.

Depreciation was allowed for in a somewhat irregular way. Often it was inadequate and had to be made up in a capital reduction.

Capital figures are those in balance sheets, and as inventories were liable to fluctuations they are only a moderate indication of the average capital employed throughout the year.

Goodwill and the value of patents have been excluded. Although a case can be made out for including them they were often valued at a figure which bears no real relation at all to their market value.

For these reasons the percentages are liable to considerable inaccuracy, and although given correct to one decimal place, may easily contain errors of 10%.

Where published information is particularly deficient, but not absent, estimates are given as very approximate (e.g. c 6.5).

Source: Company Balance Sheets, profits and loss accounts and Company Reports.
The demand for plant for factory electrification rose after 1903 just when central station demand was declining. Also home manufacturers were able to turn to the market for factory plant, concentrating on central station work. Significantly perhaps it was the German manufacturers who did. After 1904 demand rose again in Germany. The

Table 75.

Purchases of tramcars by Tramway Undertakings in Britain 1904 - 11

<table>
<thead>
<tr>
<th>Year</th>
<th>2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>1904</td>
<td>735</td>
</tr>
<tr>
<td>05</td>
<td>577</td>
</tr>
<tr>
<td>06</td>
<td>453</td>
</tr>
<tr>
<td>07</td>
<td>534</td>
</tr>
<tr>
<td>08</td>
<td>467</td>
</tr>
<tr>
<td>09</td>
<td>386</td>
</tr>
<tr>
<td>1910</td>
<td>338</td>
</tr>
<tr>
<td>11</td>
<td>329</td>
</tr>
</tbody>
</table>

Year ending December for companies. Year ending March 31st in the following year for municipalities. The figures cover 80 - 90% of tramway undertakings.

Source: Board of Trade Returns.

Profits when traction demand fell. Table 76 shows how traction orders, previously at a high level, fell off sharply in 1907, while other orders remained steady.
Table 76.

<table>
<thead>
<tr>
<th>Year to March</th>
<th>Traction equipment</th>
<th>Other equipment</th>
<th>Contracting</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1906</td>
<td>266,853</td>
<td>403,194</td>
<td>152,599</td>
<td>843,646</td>
</tr>
<tr>
<td>7</td>
<td>61,344</td>
<td>413,629</td>
<td>160,321</td>
<td>635,290</td>
</tr>
<tr>
<td>8</td>
<td>29,241</td>
<td>426,759</td>
<td>125,737</td>
<td>583,757</td>
</tr>
<tr>
<td>9</td>
<td>25,777</td>
<td>376,116</td>
<td>119,132</td>
<td>521,025</td>
</tr>
<tr>
<td>1910</td>
<td>34,540</td>
<td>391,011</td>
<td>99,314</td>
<td>524,865</td>
</tr>
<tr>
<td>11</td>
<td>34,441</td>
<td>506,214</td>
<td>103,524</td>
<td>644,179</td>
</tr>
</tbody>
</table>

Source: B.T.H. Historical Statistics.

1. Major firms had amalgamated into three big groups: A.E.G., Siemens-Schuckert, and Felton & Guilleaume - Lahlmayer Werke, and there ceased to be any... low tendering for British central station contracts. Instead German manufacturers, particularly A.E.G., turned to industrial work.

2. A.E.G. had been selling electric power transmission plant both d.c. and 3 phase a.c. in England since the middle nineties, and the lack of interest of English manufacturers in polyphase a.c. gave them a good start. In the years 1904 - 10 a great deal of A.E.G. plant must have been sold in this country. It was said that a great deal of the electric plant in the South Wales coalfield was supplied by them. In Lancashire many installations were also made by A.E.G.

1. A.E.G. absorbed the Union Electric Co. (Vereinigte Elektrizität Gsellschaft.)
Profits seem to have been rather higher in factory electrification than central station work. As Table 74 shows E.C.C., concentrating on the former made better profits than many firms. As Table 69 shows output was high in 1906 - 9 at a time when central station demand was low. The Lancashire Dynamo and Motor Co., which concentrated on standard a.c. and d.c. motors and generators for factory electrification did very well. No accounts were published but in a letter to the Electrical Review in 1907 it stated that profits were good and that 8½% p.a. had been paid on the ordinary shares for the last six years.

But there are also differences between the profitability of firms which do not seem to be accounted for by the differences in conditions in different segments of the market. As Table 69 shows despite all the sorry stories of the other electrical manufacturers British Electric Transformer continued to make high profits throughout the period. Also the fortunes of firms could fluctuate sharply. Bruce Peebles and Co. is a good example of this. The company was registered in 1903, having been a private firm beforehand. Turnover grew up to 1907, the works seem to have been fully employed and profits were high. Then excessive lending to customers led to liquidity difficulties and the firm had to be reconstructed. For the next few years profits were very low.

1. Edn. Vol. 61, P 163. 2 August 1907.
The recession in prices from 1901 and the slow growth of demand caused difficulties similar in kind, but more acute in degree, to those of the early and middle nineties. In January 1905 the Electrical Review pointed out that in 1904 engineering shops were only partially filled with orders at unremunerative prices. Prices had fallen in the last 3 years to an extent "which would have scarcely been thought possible." Two years later the Electrical Review commented that the manufacture of electrical machinery had become distinctly unprofitable. Prices, it was said had fallen 30 - 40% in the last 3 - 4 years. Low prices were the trouble.

"There has been a moderate demand for electrical plant for some time past, and the condition of many of the principal workshops suggests that they are well off as regards output, but on every hand one hears the lament of low prices .... one has witnessed a rather curious phase in selling which has at some time or other affected nearly every firm. With the prospect of empty shops many firms have rushed into the market and procured work at any price and after a few repetitions of such actions .... a close student of affairs must have long recognised that, despite the considerable demand for heavy machinery this section of the industry is suffering from over production."

Prices continued to fall; in the three years 1905 - 08 they were said to have fallen another 25%.

The period of falling profits was a long one, extending from 1900 to 1910. It began earlier than one might have expected because of Continental competition in the years 1900 - 04. It was not a period of rapid decline; it was a long slow squeeze. Profits were often below the long term rate of interest, but were very rarely negative. In a way this

3. Crompton Company Reports.
was unfortunate; capacity was not reduced as it might have been if profits had fallen further and faster. Only one electrical manufacturer went out of business, T. Parker Ltd., which was, significantly one of the smaller firms. Mechanical engineering firms with small electrical departments would be in no mood to abandon them as they were probably not unprofitable compared with mechanical engineering products, and future prospects always seemed promising.

As Table 77 shows financial assets did not rise as they did in the 1890s. But increases in the volume of output still put severe financial strain on firms. This strain is best documented in the case of Brush. From 1900 onwards the expansion of working capital was financed by loans. In 1902 there was already an overdraft of £25,000 with Parr's Bank. In the same year it had to be increased to £40,000 because of increases in work in progress and the difficulty of collecting money owed to the company. Two months later it had to be increased to £50,000. By December 1903 not only was £55,969 owing to Parra, but there was a new overdraft with the London, City and Midland Bank of £34,902. In February 1904 Parrs Bank asked for the overdraft with them to be reduced. The next attempt at raising money was in March 1904 when the Chairman (Lord Vaux) arranged a loan, £15,000 at 5½ in his own name on the security of 2,000 British Electric Traction shares held by Brush. Brush had also been borrowing direct from B.E.T. The difficulty of getting enough money to carry out orders when in this situation was strikingly shown when Brush was awarded a contract for seven complete electric trains for the London Underground in May 1904. They were to be delivered between

1. What follows is based on the minutes of the Brush finance Committee from 1902 to 1908. Brush Historical Records.
September 1904 and January 1905 at a total price of £75,674. Brush wrote to B.E.T. with a request to borrow £10,000 for this contract. They proposed 4½% Bills; five at £1,500 to mature on 30th September, and intervals of one month successively, and one of £2,500 to mature in February 1905.

The absolute size of short term indebtedness can be seen from the position of April 1905. £120,778 was outstanding at the time, while the total value of stocks and work in progress in June 1905 was £151,511. Brush was continually bumping along the ceiling of short term borrowing. After 1905 borrowing from B.E.T. and Parrs Bank rose, although other short term debts fell. By July 1906 £75,083 was owing to Parrs and the bank wanted it reduced to £50,000 and declined the Brush request for an advance of £40,000 on the specific security of the St. Petersburg Trams contract. At the same time B.E.T. wanted the load of £50,000 to be repaid in instalments of £5,000 per month. Thus Brush was forced at a bad time to raise £79,765 on debentures, a move accompanied by a reduction in capital.

British Westinghouse, B.T-H., Siemens Bros. Dynamo Works and G.E.C. were fortunate in possessing extra sources of funds. British Westinghouse was very heavily financed from Pittsburg. At the end of 1906 total expenditure on capital account was £4.79 million. The American

1. Made up as follows: £
   B.E.T. 30,740
   Lord Vaux (Chairman) 13,058
   Parrs Bank Loan 26,000
   " " Overdraft 11,742
   Chartered Bank of India 29,238
   £120,778

2. Expenditure on patents, factory, plant, inventories and work in progress, net trade lending, shares in other companies and experimental work.
### Table 77.
#### The Expansion of Assets 1904 - 10.

<table>
<thead>
<tr>
<th>Company</th>
<th>Increase in fixed assets after depreciation</th>
<th>Increase in stocks and work in progress</th>
<th>Increase in financial assets</th>
</tr>
</thead>
<tbody>
<tr>
<td>British Westinghouse</td>
<td>£ -8,106</td>
<td>£ -326,904</td>
<td>£ 124,489</td>
</tr>
<tr>
<td>(July 1904 - Dec. 1909)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B.T.H.</td>
<td>£ 83,866</td>
<td>£ 31,704</td>
<td>£ -483,558</td>
</tr>
<tr>
<td>(March 1904 - 1910)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dick, Kerr &amp; Elect. Rly. &amp; Carriage Co.</td>
<td>£ 70,654</td>
<td>£ -39,645</td>
<td>£ 178,598</td>
</tr>
<tr>
<td>(June 1904 - 1910)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Siemens Bros. Dynamo Works</td>
<td>£ -74,847</td>
<td>£ 280,414</td>
<td></td>
</tr>
<tr>
<td>(Dec 1904 - 1909)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G.E.C. (Witton Works)</td>
<td>£ 6,519</td>
<td>£ 2,472</td>
<td></td>
</tr>
<tr>
<td>(Dec 1906 - 1910)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brush</td>
<td>£ 9,567</td>
<td>£ -148,479</td>
<td>£ -71,280</td>
</tr>
<tr>
<td>(Dec. 1903 - 1909)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crompton</td>
<td>£ 387</td>
<td>£ -54,155</td>
<td>£ 69,026</td>
</tr>
<tr>
<td>(March 1904 - 1910)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E.C.C.</td>
<td>£ -11,365</td>
<td>£ -4,849</td>
<td>£ -57,260</td>
</tr>
<tr>
<td>(May 1904 - 1910)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>British Electric Transformer</td>
<td>£ 4,811</td>
<td>£ -2,927</td>
<td>£ -619</td>
</tr>
<tr>
<td>(Dec. 1904 - 1909)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. Work in progress is under "debtor".


3. Heavy plant manufacture was only a part of the activities of G.E.C.

4. No allowance made for special write off when Brush capital was reduced in this period.

Source: Company Balance Sheets.
### Table 78.

**The Source of Funds 1904 - 1910**

<table>
<thead>
<tr>
<th>Company</th>
<th>Borrowing on ordinary shares</th>
<th>Borrowing on preference shares</th>
<th>Borrowing on debentures</th>
<th>Loans</th>
<th>Retained Profit before depreciation</th>
</tr>
</thead>
<tbody>
<tr>
<td>British Westinghouse (July 1904 - Dec 1909)</td>
<td>£864,300</td>
<td>-176,036</td>
<td>-8,248</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B.T. L. (March 1904 - 10)</td>
<td>-7,060</td>
<td>-200,750</td>
<td>-339,080</td>
<td>115,713</td>
<td></td>
</tr>
<tr>
<td>Dick, Kerr &amp; Elect. Rly. &amp; Carriage Co. (June 1904 - 1910)</td>
<td>100,000</td>
<td>-32,212</td>
<td>42,387</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brush (Dec. 1903 - 1909)</td>
<td>79,765</td>
<td>-100,000</td>
<td>29,382</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crompton (March 1904 - 1910)</td>
<td>9,375</td>
<td>38,770</td>
<td>31,283</td>
<td></td>
<td></td>
</tr>
<tr>
<td>British Electric Transformer (Dec. 1904 - 1909)</td>
<td>1,153</td>
<td>5,061</td>
<td>25,418</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Source: Company Balance Sheets.*
company had provided £3.74 million. It had also lent money to British Westinghouse's customers, principally the Mersey Railway and the Clyde Valley Power Co. through Traction and Power Securities Ltd. Then in 1907 this source of support was suddenly cut off when the parent company fell into the hands of the Receiver as it was unable to meet its short run financial obligations in the panic of that year. Short run loans from the American Westinghouse company were considerable - amounting to £136,374 in July 1907. Thus British Westinghouse was forced to go to the British capital market, at a time when the company's fortunes had been very low for several years. However £245,000 was raised on 6% prior lien debentures.

It is not known how much General Electric provided to establish B.T.H.'s Rugby factory. But short term lending was considerable. By March 1905, £674,319 had been borrowed from General Electric and although the subsequent fall in business enabled this to be reduced to £174,098 by March 1910 it began to rise from then onwards as business expanded.

Falling profitability and general financial stringency were associated as in the nineties with a slow rate of technical progress. The new firms and new products of the years 1897 - 1904 seemed to have brought British electrical machinery manufacture up to date again, but there was soon evidence of lagging behind Germany and the United States. The gap never became as large as it had in the nineties, although this was partly at least because of the different possibilities of technical progress. In the nineties there were important new things to be developed; traction.

1. S.R. Saul, op.cit.
polyphase a.c., much bigger generators with different types of prime mover. After 1900 - 03 all these things had been introduced, and possible changes were all in the nature of a stream of small improvements.

Unfortunately the evidence is inadequate to attempt any precise measure of the length of the technical lag. It does however seem to have varied with different products, and was perhaps longest in big generating plant. For example K. Baumann told the Manchester section of the I.E.E. in January 1912 that "the increase in the output (size) of turbo alternators has been more rapid in the U.S. and on the Continent than in this country." The municipalities also seem to have felt that British made central station plant was somewhat inferior. Defenders of the unprofitable performances of the electrical manufacturers state that this was mere prejudice but there is considerable evidence to show that municipalities preferred English plant, and only bought German plant because it promised lower operating costs or was cheaper. And on the whole it was not cheaper. English buyers preferred English cables, and there are many cases where they bought English cables at prices above those of German cables. Why should they behave differently over electrical machinery? Left wing municipalities had a reason additional to patriotism and easy access to makers should the plant not operate well, the desire to raise wages by stipulating that the contract be carried out at Trade Union rates. The L.C.C. and many of the London Borough did this and such a clause effectively excluded foreign tenders.

1. British Westinghouse's new Chief Mechanical engineer.
Hermann Levy, writing in 1908–9 pointed out the "greater reported utility" of German, Belgium and U.S. electrical machinery over that of English manufacturers - "a fact often neglected by, or underestimated by, complaining British producers but well supported." In this context it is useful to look at the foreign trade statistics of value per ton of electrical machinery. Technical progress reduced the weight of products for a given capacity. The following figures of the value per ton of electrical machinery exported from and imported into Britain from 1904 to 1913 suggest that Britain was exporting less developed machinery and importing more highly.

<table>
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<tr>
<th>Year</th>
<th>English Exports</th>
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<th>English Imports from U.S.A.</th>
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<tr>
<td>13</td>
<td>85</td>
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</table>

developed machinery by 1910-11 although she had not been doing so in 1904-5. This is consistent with slower technical progress, but this evidence is not conclusive. English exports were largely to the Empire, where electrical development came a little later than in England. Thus smaller, simpler plant was often more appropriate. It is also possible that there were systematic shifts in the type of electrical machinery involved.

Despite the association between low profits and slow technical progress, the possible connections between the two are not clear. Evidence is rather scanty. In some ways the very strong competitive pressure of the years 1901-10 could be expected to be a stimulant. Successive small improvements could be introduced into successive contracts. Firms competed both by giving better guarantees as to performance than competitors, and by tendering lower prices. They tried to reduce manufacturing costs by cheaper designs of machinery. But matters did not seem to work in this way. Perhaps this was partly because the profit squeeze went on for so long that it became enervating or perhaps slow technical progress was connected with the relations between manufacturers and customer, and with the position of the consulting engineer.

The situation then was different from that of the nineties in that there does not seem to have been as large a rift between engineers and business men. Yet there was a growing feeling that there was a gap between

1. As this covers matters rather wider than manufacturing, this issue will be postponed to Chapter 11.
the two which ought to be filled. There was considerable support in electrical engineering circles for the view that what was needed was a generation of "commercial engineers - or engineer traders". The lack of enough people who could combine engineering and business was an important deficiency in the British economy at the time. However it seems to have been most noticed in electrical engineering circles, and this may indicate that the effects of this deficiency were more marked in electrical machinery manufacture than in other trades. The Americans and the Germans were supposed not to suffer from this lack of commercial engineers and thus it is interesting to see that British Westinghouse, E.T-H. and Siemens Bros. Dynamo Works were as unsuccessful as any manufacturers. This tends to direct one's attention towards difficulties like the structure of the market or the slow growth of demand for electrical machinery in Britain, if one seeks to explain the slow technical progress.

It was also argued by many contemporaries that English firms were backward compared with the Germans and Americans, not only in their engineering developments, but in their market behaviour. The complaints were subsumed under "selling" deficiencies. English firms waited for orders and did not actively stimulate business. This was said to be one reason for the slow development of their electric power equipment business. This point has been made elsewhere; in essence it is that manufacturing firms could increase sales by reducing uncertainty as to the relative cost of electric and mechanical power transmission. It was argued that this

could only be done adequately if good commercial engineers were employed to seek orders. This is what the Americans did, this is what A.E.G. did in South Wales.

Concentration remained high. In 1907 we can look at this for the whole electrical machinery group. Gross output figures are given for some of the major firms in Table 79. Unfortunately for Siemens and Dick, Kerr estimates have had to be made. Because there are no output figures at all to guide ones crude estimating procedure, the Dick, Kerr figures are rather speculative. The 1907 Census gives the output of electrical machinery plus arc lamps at £4,541,000. To this we must add something for contracting. As most contracting work was done by cable makers and firms doing only contracting, I have taken a third of the total. Thus total output of machinery firms is assumed to be £4,967. If all the assumptions made are correct the four major firms, British Westinghouse, B.T-H. Dick, Kerr and Siemens accounted for 57% of total output.

Concentration however varied in different segments of the market. The market for central station generators, as can be seen from Table 81 was rather more concentrated. The market for large central station generators, i.e. 1000 KW and above was even more concentrated. In the years 1903 - 6 it was largely in the hands of four main producers,

1. N.B. The Dick, Kerr output included tram car bodies.
Table 79.

Gross output of electrical machinery of various firms 1900 - 1913, £000

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Firms drew up their accounts at different times. All figures are put under the nearest calendar year.

1. British Westinghouse.

2. Orders. Sales (including incandescent lamps which have been excluded from orders) 1900, £539,401; 1909, £535,065; 1911, £578,067; 1912, £388,904; 1913, £1,155,620.

3. Dynamo, Electrical Installations and Electrical Trade Dpts. at Woolwich 1900 - 02. Siemens Bros. Dynamo Works 1911 - 13. From 1907 - 1910 output has been estimated from stocks using a stocks output ratio of 0.45.

4. Estimated throughout from stocks using a stocks output ratio of 0.45.

For comments on the use of stocks output ratios see Appendix.
| Year | Siemens | L.C.O. | Druck | Crompton | Ferranti | Siemens & Halsall | Vitting F. Brown | Boveri, cie | Electrique et Hydraulique | International Electrical Engineering | Continental Firms | Lucas |电机
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For method of calculation see Appendix P 507

Source: Electrical Trades Directory.
Table 81.

The market for central station generators

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<th>% imports</th>
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British Westinghouse, B.T-H., Dick, Kerr and Parsons. Subsequently the share of Parsons declined and Siemens joined the other three in the first rank of quantitative importance.

The market for traction plant was much more concentrated. Five home producers supplied this market and other firms were scarcely involved at all. They were British Westinghouse, B.T-H., Dick, Kerr & Co., Brush and Siemens. At first B.T-H. and British Westinghouse provided most of the motor equipments, but by 1901-04 they were joined by the other three. Information is available about tenders for tramway motor equipments and in nearly all cases only these five firms tendered.

British Westinghouse, B.T-H. and Dick, Kerr nearly always tendered. In the case of electric railway motors and equipment, concentration was even higher. The London Underground Railways had their motor equipments supplied almost entirely by B.T-H. and British Westinghouse. The only exceptions were the short Waterloo & City line and the City & South London Railway. Westinghouse equipped the Mersey Railway. The two pioneer main line electrification schemes, the North Eastern and the Lancashire and Yorkshire were equipped electrically by B.T-H. and Dick, Kerr respectively. The only other big scheme completed before 1914 was that of the London, Brighton and South Coast Railway. A.E.G. provided

1. Assuming Westinghouse and B.T-H. imported all their plant from the American parents up to and including 1901 and manufactured all their plant in England from 1902 onwards.

2. Siemens traction equipment seems to have been made in Germany before the opening of Siemens Bros. Dynamo Works traction department at Stafford in 1904.

3. See Table 82 for number of firms tendering. More firms tendered for laying the line, cables and overhead wires, but this is a different matter.

4. See T.S. Lascelles. The City and South London Railway P 34 for details of the makers of electric locomotives.
all the motor equipments. The smaller schemes were the Bury-Holcombe Brook line of 1912, extended into the Bury-Manchester line, the re-equipping of the Liverpool Overhead Railways with more powerful motors, and the Heysham, Morecambe and Lancaster line of 1909. The electrical equipment was provided by Dick, Kerr for the first two, and by Siemens and Westinghouse for the third.

High tension, heavy power switch-gear was also rather highly concentrated. Switchgear developed as a separate branch of electrical engineering from the beginning of this century with the advent of large power circuits at high voltages. In the last few years of the 19th century two firms were outstanding in developing switchgear, Ferranti and B.T-H. In 1894 Ferranti first put switches into individual cells. In the following year he designed the first oil break switch. B.T-H. laid the foundations of its switch gear engineering when carrying out the Central London Railway contract. In 1903 - 4 B.T-H. and Ferranti were the two major high tension switchgear manufacturers. It was also at this time that the firm of A. Reyrolle & Co. began to become important. Reyrolle, a Frenchman who had set up a workshop in London in 1886, did a lot of switchgear work for B.T-H. in the late nineties. In 1901 he expended his business into a private company and bought a works at Hebburn, Near Newcastle. In 1905 he was joined by H.W. Clothier who had been with

1. Higher voltages increased the chances of arcing. Higher power (k.v.a.) on circuits meant that any faults which would cause circuit breakers to intercept the current could lead to mechanical strains of explosive force within the circuit breaker itself. For the development of switchgear see H.W. Clothier. op.cit.


3. Came to England 1883 and worked for 3 years with a firm of scientific instrument makers.
Ferranti. He very quickly developed the now famous Reyrolle metal clad switchgear. The first installation was made by Reyrolle in 1906. Low tension switchgear was made by a large number of firms.

On the other hand the market for electrical machinery for factory electrification was much less concentrated. A number of mechanical engineers and tool makers were drawn into electrical engineering in the years 1888 - 91. The beginnings of factory power after 1901 drew in many more. The range of uses for electric motors was very wide, from steel rolling mills to spindles, and was to some extent segmented, with a few firms supplying particular types of motors. This was partly because mechanical engineers would concentrate on building motors for their range of machine tools. But motors could never be as differentiated as tools, and thus the degree of competition between the various segments of the market must have been high. Also the electrical manufacturers did not specialise in any one part of the motor market. Taking factory electrification machinery as a whole, literary evidence suggests that the major producers had a fairly large share of the market, although below that for central station plant, but that there was a long tail of small producers.

This rather sparse information on the structure of sellers can be added to by data derived from published tenders. Most tenders were not published but there were still quite a large number which were. They indicate the number of firms in each section of the market. But they only relate to utilities. The information is given in Table 82. Firms did not tender for all contracts. This is noticeable in rotating plant, switchgear and transformers, but not in cables and traction equipment.
Table 82. Electrical plant & machinery sold to utilities. Number of firms tendering.

<table>
<thead>
<tr>
<th>Year</th>
<th>Cables</th>
<th>Rotating plant</th>
<th>Switchgear</th>
<th>Static Transformers</th>
<th>Traction Equipment</th>
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(1) Average number of firms tendering for each contract.
(2) Number of contracts for which such details were published.

Rotating plant is principally generators, rotating converters, large motors. The figures are of firms who were also manufacturers. It is however impossible to guarantee that all agents tendering plant not manufactured by themselves are excluded.

Source: Tender details published in the Electrical Review.
### Table 83.

**Rotating plant for Central Stations. Firms tendering for and supplying plant.**

<table>
<thead>
<tr>
<th>Year</th>
<th>(1) Firms tendering for rotating plant. Average per contract</th>
<th>(2) Firms supplying central station generators. Total p.a.</th>
<th>Proportion firms tendering for each contract 1 year moving average (1)</th>
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<tbody>
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</table>

**Source:** Tender details for Col. 1 and Electrical Trades Directory for Col. 2.
In the case of rotating plant we can put together, as has been done in Table 83 the total number of firms supplying plant and the average number tendering in any one year. The ratio between the two is steady in the long run.

In the depressed oligopolistic situation of electrical machinery manufacturing one would expect some type of association between firms. There were attempts to form some agreements, but until after 1914 they were almost entirely unsuccessful. Electrical manufacturers first began to consider combination over the harsh conditions of contract imposed on them by the municipalities. After the experience of the early nineties, the principal manufacturers came together in 1895 to try and change the usual conditions of contract. In March 1896 the Electrical Review reported that there were rumours that existing manufacturers were "taking counsel together." The rumours were correct and the substance of the matter is given in a letter from R.E.B. Crompton to J.P. Albright, dated 24 February 1896. Crompton says:

"I am sure you will be glad to hear one thing, which is that after a good deal of trouble we have at last got nearly all the principal manufacturers to agree to form an Association to be kept as quiet as possible, first for the purpose of agreeing to boycott certain clauses in specifications .... second to agree to insist on better terms of payment in municipal contracts (i.e. more rapid payment) .... thereby limiting the power of the consulting engineer .... The last firm to join has been Parker. Everyone is in it but Siemens and Siemens' people are quite ready to join but Siemens himself is away in the Amazons."

The Association (the Electrical Plant Manufacturers Association) entered into negotiations with the Municipal Electrical Association to

2. Crompton Historical Records.
establish standard clauses governing the relationship of consumers, manufacturers and consulting engineers. By March 1898 commercial conditions had been dealt with and it was hoped that more would be done by standardising many technical features. Brush, Crompton, the E.C.C., Ferranti, Fowler and Johnson & Phillips were the manufacturing firms involved. The Association does not seem to have thought of price agreements or market sharing.

This document had little effect on practice. Municipalities still proposed harsh condition in their specifications and these were accepted. Representations were made to the Institution of Electrical Engineers and in December 1900 a committee was formed to prepare a draft set of "model clauses". Representatives were recruited from the Municipal Electrical Association, the Electrical Plant Manufacturers Association, the Cable Makers Association and the Engineering Employers Fund. In April 1902 a draft of these clauses was published. Their

1. The following model clauses were drawn up:

(a) Extra and additional drawings to be paid for.

(b) Variation of works by (consulting or municipal) engineer on the spot to cause adjustment to the contract price.

(c) Penalties for non completion of works not to exceed 1% per week of contract value.

(d) Rent of 5% p.a. to be paid if works used before contract completed and paid for.

(e) Payments were to be made in each month for 75% of the work done in the month until the 25% balances added up to 10% of the total contract. Then 90% of the work done in each month was to be paid for each month.

(f) Maintenance by contractors, save for fair wear and tear, to be up to 12 months only.

(g) Disputes were to be settled by arbitration.

intention was like the 1898 clauses to redress the balance in favour of tenderers. But this latter document had no more effect. In May 1900 the Electrical Review commented that the I.E.E. model conditions had not come into general use. Contracts, as one might expect in view of the depressed state of the industry, were still very hard on contractors, particularly with respect to terms of payment, absence of arbitration clauses and abnormally heavy penalties for late delivery or failure to meet guarantees.

Other attempts to restrain competition had no better results. In 1902 the National Electric Manufacturers Association (N.E.M.A.) was formed. Its members however did not include the biggest manufacturers. British Westinghouse for example did not join until 1909. Largely because the largest firms were outside, it achieved little. In 1909 its past achievements were said to be concerned with "railway rates, customs classifications, specifications, fire insurance, exhibitions, Christmas boxes and other trade abuses, the establishment of a benefvolent fund .... The tone of N.E.M.A.'s annual reports confirms this. It was not intended as a body for restricting competition, but "to represent the views of its members in matters of general interest to the industry." Yet it was clearly hoped that something might be done about prices under the N.E.M.A. umbrella. In some branches of the trade this did happen, by

3. E.R. Vol. 64, P 950 11 June 1909
1907 the conduit makers had "formed an association for the better safeguarding of their particular interests." The Electrical Review commented in 1907 that "in some smaller lines the members of certain trades who happened to be members of the Electrical Manufacturers Association were reported to be successful in efforts to raise prices when raw material prices rose."

But in generators, motors and other heavy machinery nothing was achieved despite a serious attempt to reach an agreement in 1907. In January the Electrical Review said,

"We are told that attempts are being made to bring manufacturers together again for the purpose of correcting prices, but while most firms have evinced a readiness to participate in such an agreement, we fear the movement is not likely to succeed because it is commonly understood that 2 or 3 firms are strongly opposed to a combination." 3

Its prediction was confirmed nine months later by a letter from A.P. Wood, the General Manager of the Lancashire Dynamo and Motor Co. He said,

"Some months ago various manufacturers of dynamos and motors made a strenuous effort to regulate the prices of electrical machinery. They got out a complete scheme for the working of this, which met with the unanimous approval of all the members, yet three or four of the largest firms in the country definitely refused to come in and the scheme had to be abandoned. In view of this, and also of the fact that there are so many dynamo manufacturers in this country, it seems to be practically impossible to get a scheme together for a general regulation of prices." 4

2. E.R. Vol. 61. P 432. 13 September 1907. There was an early pricing for example in meters and we may suppose it was in operation by 1907. Also there were agreements in electric lamps.
A "Manufacturer" writing in the *Electrical Review* in 1908 put a similar viewpoint. Several times in the past, he argued, manufacturers had tried to arrange matters together with a view to agreeing on conditions of contract, and limiting the fierceness of the competition at present existing between them, but they were unable to agree among themselves; or, having agreed, were unable to abide by their undertakings. Although only 10 - 15 firms were involved, he had no high hopes of future agreement. He argued firstly that there were both healthy and unhealthy firms and that any agreement would handicap the former. Only after some elimination of weak firms would combination be possible. Secondly he argued that the big four had divergent interests. Dick, Kerr had British management and was financed at home. British Westinghouse was of American origin, and was still run by Americans, although it had been financially disinherited by its parent. British Thomson-Houston and Siemens were controlled and financed by Americans and Germans respectively.

In the event there was no elimination of "unhealthy" firms, but the improvement in trading conditions in 1911 - 12 did provide much better circumstances for price agreements. In 1911 N.E.M.A. was reconstructed as the British Electrical and Allied Manufacturers Association (B.E.A.M.A.). This time all the major manufacturers were members. From about 1912 there were some price agreements relating to the turbo generating plant. In 1913 the first agreement was signed relating to the prices of small motors and generators. In the same year five transformer manufacturers joined together to operate a notification agreement, and three years later began to arrange common prices.

1. *E.R. Vol. 63, PP 566 - 7. 20 October 1908. The Proposed Electrical League and criticism from a Manufacturers point of view, by "Manufacturer."*
All this contrasts sharply with the situation in the cable making section of the industry. In 1899 the Cable Makers' Association was formed. Ostensibly it was to prevent deterioration in quality which firms in the industry felt was taking place owing to competition. Firms joining agreed to accept as a minimum the prices then ruling and to compete only in quality. The cables of three grades then most in use were standardised both as regards weights and resistances of the copper conductors, the thickness of the dielectric, and the protecting coverings overall. In 1900 the C.M.A. suggested contract terms for the supply of electric supply mains. These were similar to those suggested by the Electrical Plant Manufacturers Association and Municipal Electrical Association in 1898. But in practice the cable makers were able to exercise much more influence on municipalities than the electrical machinery makers. They struck out clauses in specifications which they objected to, and were often awarded the contract despite this.

They were successful for two reasons. Firstly the internal discipline of the group was much greater than that of the machinery makers. Concentration seems to have been higher. The trade in electric light and power cables was dominated by British Insulated Wire and Callanders, although eight or nine firms regularly tendered for contracts. As can be seen from Table 84 the product was much more standardised than most

3. In 1902 it took over the Telegraph Manufacturing Co. and became British Insulated & Helsby Cables Ltd.
The average of the variance of tenders submitted for each contract. To allow for differences in the size of contracts, all tender prices were expressed as a percentage of the average tender price for a contract. The variance of these percentages was then calculated.

Source: Calculations from tenders published in the *Electrical Review*.

machinery and the C.M.A. reduced heterogeneity by introducing minimum standards. Thus competition other than on price was reduced. Any shading of prices was more obvious to the group than would have been the case with a more differentiated product. Individual firms had thus less incentive to reduce prices, as such reductions would be obvious and likely to be followed by other firms.

Secondly English cable makers were not at the same cost disadvantage compared with foreign competitors as electrical machinery manufacturers were. Technical progress was much slower in cables, and quality was primarily improved by careful manufacture and the use of high quality materials. Although English cable makers do not seem to

Table 85

Profits of cable makers. Annual profits as % of Fixed Capital. Inventories, work in progress and shares in other companies.

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2. India Rubber and Cutta Percha Co.

3. Telegraph Construction and Maintenance Co.
Tel. Con. and I.R.G.P. were largely concerned with telegraphic cables.

Sources: Company Balance sheets and Profit and Loss accounts.
have given the same attention to research as did the Germans, they were not left behind in the years 1904 - 10 as were manufacturers of electrical machinery. This seems partly to have been because cable design was not changing as fast as machinery design at the time, but the effect of the price agreement in keeping up profits may have helped by providing adequate development resources. Cable makers profits are shown in Table 85.

Because there was no appreciable gap between the quality of British and Continental cables British Cable makers were able to exploit the preference of municipalities for British plant. There are numerous cases, especially in London, where municipalities disregarded foreign cable tenders although at prices below those of home manufacturers, principally because no one could be sure that they would comply with the fair wage clause. This gave cable makers a protected market, with an inelastic demand, and they seem to have practised some price discrimination, charging less to company purchasers where the elasticity of demand for their products was higher.

After 1910 the demand for electrical machinery began to expand rapidly again. Exports had been rising since 1908 as manufacturers were driven to seek overseas markets by the low demand at home. British Westinghouse with considerable surplus capacity had turned to exports between 1905 and 1907; they were trebled in value in these years. Foreign competition at home had declined as prices fell. In the years
1900 - 04 there were 16 agencies of large Continental firms in this country. By 1909 only 5 remained.

But it was the rise in home demand which provided the main force behind the upswing. This seems principally to have been a rise in the demand for plant for factory electrification. The output of plant for this purpose is probably underestimated in Table 69. This upswing merged into a wartime boom, which was the product of further increases of demand for plant, primarily for factory electrification, and the interruption of imports. The profits of most companies rose. There was in general little expansion of capacity, usually firms merely achieved full capacity working. The only firm to expand capacity was British Thomson-Houston. A new lamp factory was built at Willesden to help the Rugby lamp factory meet the increased demand for metal filament lamps, and new plant was laid down for heavy equipment manufacturing. An extra 150,000 square feet was added to the 500,000 square feet of floor space from 1902.

Little of note happened in this period. Economically it was simply a period of recovery from bad conditions. Technically there were no big changes. The only significant technical change was in connection with turbines. After the success of the Parsons turbine, other manufacturers began to make steam turbines. Parsons built the whole

1. IS Foreign Competition Overrated? by A.G.M. E.R. Vol. 64. Pp 1026 - 7. 18 June 1909. "...when the German sees that there is no reasonable profit left he withdraws from the competition; our home firms on the other hand go on paring prices down until they cannot get enough cut of a contract to meet office, etc. expenses."
<table>
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<tr>
<th>Company</th>
<th>Increase in fixed assets after depreciation £</th>
<th>Increase in stocks &amp; work in progress £</th>
<th>Increase in financial assets £</th>
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<td>165,976</td>
<td>-43,042</td>
</tr>
<tr>
<td>Dick, Kerr &amp; United Electric Car. (June 1910 - 1913) (after sales)</td>
<td>-25,844</td>
<td>77,745</td>
<td>2,263</td>
</tr>
<tr>
<td>Brush (Dec. 1909 - 1913)</td>
<td>-5,084</td>
<td>33,963</td>
<td>-36,206</td>
</tr>
<tr>
<td>Crompton (March 1910 - 1914)</td>
<td>45,423</td>
<td>-31,603</td>
<td>-53,209</td>
</tr>
<tr>
<td>E.C.C. (May 1910 - 1914)</td>
<td>6,736</td>
<td>18,652</td>
<td>-40,304</td>
</tr>
<tr>
<td>Bruce, Peebles (Dec. 1909 - 1914)</td>
<td>712</td>
<td>23,197</td>
<td>-15,246</td>
</tr>
<tr>
<td>G.E.C. (Witton) (March 1910 - 1914)</td>
<td>-6,968</td>
<td>116,952</td>
<td>18,452</td>
</tr>
<tr>
<td>British Electric Transformer (Dec. 1909 - 13)</td>
<td>14,245</td>
<td>21,779</td>
<td>16,319</td>
</tr>
</tbody>
</table>

1. To Dec. 1912 for shares in other companies. Dec. 1913 figure not available before write off.

2. Work in progress is under "debtor".

3. Reconstructed 1912. Some write off may be unallowed for. Increase in financial assets excludes changes in shares in other companies where there is clearly a big write down.

4. 1913 accounts not available.

5. Creditors include loans from Siemens-Schuckert.

Source: Company Balance Sheets.
Table 87.

The Source of Funds 1910 - 1914

<table>
<thead>
<tr>
<th>Borrowing</th>
<th>on ordinary shares</th>
<th>on preference shares</th>
<th>on debentures</th>
<th>on loans</th>
<th>Retained profit before depreciation</th>
</tr>
</thead>
<tbody>
<tr>
<td>British Westinghouse (Dec. 1909 - 1913)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1,108 350,238</td>
</tr>
<tr>
<td>B.T.H. (Mar. 1910 - Dec 1913)</td>
<td></td>
<td></td>
<td></td>
<td>-14,485</td>
<td>860,741</td>
</tr>
<tr>
<td>Dick, Kerr &amp; United Electric Carriage Co. (June 1910 - 1913)</td>
<td></td>
<td></td>
<td>-70,370</td>
<td>100,000</td>
<td>10,967</td>
</tr>
<tr>
<td>Brush (Dec. 1909 - 1913)</td>
<td></td>
<td></td>
<td>23,762</td>
<td>-13240</td>
<td>3,603</td>
</tr>
<tr>
<td>Bruce, Peebles (Dec. 1909 - 1914)</td>
<td></td>
<td></td>
<td>16,138</td>
<td></td>
<td>-4,802</td>
</tr>
<tr>
<td>E.C.C. (May 1910 - 1914)</td>
<td></td>
<td></td>
<td>-60,000</td>
<td></td>
<td>57,031</td>
</tr>
</tbody>
</table>

1. £818,731 came from General Electric.

Source: Company Balance Sheets.
generating unit from the beginning, but this practice was only partially followed in Britain. British Westinghouse built Parsons type turbo-
alternators and generators; B.T.H. built Curtis turbo-alternators. But Siemens and Dick, Kerr at first only built high speed alternators. Parsons issued licences in 1903 to three firms to make Parsons type turbines: Brush, Willans and Robinson, and Richardsons Westgarth. Willans made no electrical machinery, Richardsons Westgarth only a little. Willans made turbines primarily for coupling to Siemens and Dick, Kerr alternators.

Parsons eliminated turbine development in Britain; he had designed reaction turbines. Only B.T.H. made the other type, impulse turbines. The Parsons reaction turbine was highly efficient but it had small clearances between the blading and the casing. This often led to difficulties, not it seems with the turbines manufactured by Parsons, but with the Parsons type turbines made by Brush and Willans. General Electric, A.E.G. and Siemens-Schuckert had made impulse type turbines from the beginning. Outside England only Westinghouse and Brown-Boveri made reaction turbines. English manufacturers, except Parsons began to turn to impulse machines around 1910. Westinghouse as early as 1903 had decided to concentrate in future on impulse turbines as "experience had

1. Westinghouse bought the land rights for North America of the Parsons turbines in 1895 (H.G. Passer, op.cit. P 311)

2. A reaction turbine derives its power from the expansion of the steam as it passes through the blades of the turbine wheels. In an impulse turbine the steam is expanded between the wheels of the turbine. No expansion takes place in the blades of the wheel. After 1914 nearly all turbines were impulse-reaction, with impulse wheels at the high pressure end and reaction wheels in the low pressure end. Parsons machines to this day have preserved a very high proportion of reaction wheels.

3. Changes of steam temperatures caused differential expansion and could lead to blade stripping.
shown the advantages of impulse blading in freedom from fine running clearances and therefore from stripping. In 1909 K. Baumann was appointed chief engineer of the engine department to develop impulse turbines. He was an assistant of Professor Stodola of Zurich, one of the great authorities on impulse turbines. In 1912 Baumann was appointed chief mechanical engineer. Willans and Robinson, after their lack of success with reaction turbines, turned first to drum and disk turbines and then in 1914 to pure impulse machines. A licence was obtained from Escher Wyss of Zurich. In 1912 Brush had brought to its notice the Ljungstrom turbine developed in Sweden. It was able to deal safely with rapidly changing steam pressures and temperatures, and it promised to be more efficient (thermally) than the Brush-Parsons. But its type of construction limited its size. Its future lay in isolated rather than central station plant. Brush took out a licence and soon switched to this turbine.

In 1910 Dick, Kerr began to build steam turbines. They were to be impulse type and Dick, Kerr arranged with the patent holders, the Bergmann Company, to make their designs under licence. This move by Dick, Kerr also indicates more concentration on the manufacture of

1. J. Durnelow, _op.cit._ P 36.
2. J. Durnelow, _op.cit._ P 42.
4. Bergmann was a German Company, third in importance to A.E.G. and Siemens-Schuckert, with whom it had close financial links. The Lehmyer dynamo works of Felton and Guillaumes-Lahmeyer works had been taken over by A.E.G.
turbo-generators by the same firm. Just before the first world war Siemens Bros. Dynamo works also began to make turbines. In 1916 Willans who had thus half lost its two best customers, was absorbed by Dick, Kerr. This move towards more vertical integration seems to have taken place for engineering reasons. But it had the economic effect of increasing the amount of capital necessary to begin the production of large generating plant. Thus the distinction between central station and other generators widened further.
Chapter 9.

The Public Control of Electricity Supply and Tramways.

Much has already been published on the legislation concerning the electrical industry. In many accounts of the development of the use of electricity it has played a very important, sometimes central, role. It has been blamed for the slow development of electricity; sometimes it has been pictured as the only villain in the story. There is no doubt that many other factors played a more decisive part, yet it must be said that legislation was an important matter, and one cannot discuss the increasing use of electricity without paying attention to it. Rather than simply discussing legislation, it is better, however to put it in its proper context - as a major part of an attempt to regulate natural monopolies in the public interest.

Public utility control in its various phases from 1850 - 1950 often did have undesirable effects. This was certainly the case with electricity supply and electric tramways. But many of these effects arose almost inevitably from the attempt to devise controls when the economic atmosphere was to a considerable degree dominated by laissez-faire views. Control of electrical utilities will be looked at in this chapter from this point of view.

In the first half of the nineteenth century it was thought that competition was all that was needed to direct the individuals seeking for profits towards desirable social ends, and this doctrine was applied to what we would now recognise as natural monopolies. After 1850 this view was to a large extent abandoned, because in water and gas competition
seemed to have been positively disadvantageous as it caused excessive investment in distribution networks. Thus a new technique was tried. Natural monopolies were granted franchises which explicitly recognised their peculiar economic position but conditions were inserted to limit them where attempts to maximise profits might lead to anti-social behaviour. Early devices were maximum prices and statutory limits on dividends. It is important to notice that these conditions were established when the utility was granted its powers. No further interference with its workings was thought necessary or desirable.

The other remedy for the abuses of private monopoly was municipal operation. By the time electric lighting became commercially feasible local authorities were in many cases running gas and water supplies. This was due to the initiative of the local authorities, and not to Parliament.

The Tramways Act of 1870, introduced into Parliament because of the success of the new horse trams, is a landmark of considerable importance. Firstly, it introduced a drastically simplified procedure for obtaining franchises, and for laying down general conditions to prevent abuses of monopoly power. Intending tramway owners were to apply for a Provisional Order from the Board of Trade to operate under the general conditions of the Act. Hitherto utilities had obtained


their powers by private act of Parliament, an expensive and rather cumbersome procedure, especially as the number of utilities was rapidly rising. Secondly, the 1870 Act brought together the two methods of control, the insertion of conditions in the franchise and municipal operation. A clause provided for the compulsory purchase of a tramway by the local authority 21 years after the granting of the provisional order. The price was to be the value of the plant, and was to exclude goodwill. Goodwill was excluded from the purchase price because in the past local authorities had had to pay vastly inflated sums to purchase inefficient monopolies. Blackburn "to get these monopolists out of the way" had paid £559,000 for a gas works whose structural value was £222,000 and issued capital £235,000, and £283,000 for the water works which had had £119,000 spent on it and was of "little value" at the time of purchase. Birmingham had a similar experience in 1857.

The 1870 Act gave the towns powers to own the trams but not to run them. They had to be leased to a company which would operate them. On the other hand they could make by-laws regulating the number and frequency of trams, and these would apply even if the trams were privately owned. Municipal operation was, however, soon to follow. In 1882 Huddersfield Corporation could find no one willing to operate its policy and permit Corporations to work the system themselves unless a company made a "reasonable offer". This did not give Corporations general powers to operate the trams; in 1889 Liverpool Corporation

2. Ibid. Evidence of the Town Clerk of Birmingham.
4. Ibid.
promoted a Bill for powers to work the trams in case of need, but it was rejected by the Lords. But in the early nineties several local authorities obtained powers to work their trams under special circumstances and by 1896 powers were being freely granted to them.

Parliament was quick to investigate the possibility of legislative needs following the commercial application of electric lighting, appointing a Select Committee as early as 1879. It did not recommend any legislation but the apparently imminent widespread application of electric lighting in 1881 and 1882 quickly produced the Electric Lighting Act of 1882. It was modelled on the Tramways Act of 1870. Prospective undertakers were to apply to the Board of Trade for a Provisional Order or a licence. Licences gave rights for seven years but were rarely used. Provisional Orders were to run for 21 years, after which time the local authority could buy the undertaking at the plant value. Initially the Act was designed for close control by making Provisional Orders run for seven years only, but this was amended to 21 during the passage of the Act. There was no doubt about the rights of the municipalities to own and operate electricity supply stations; in fact the Board of Trade interpreted the Act as giving them preference over a company if both should apply for Provisional Orders at the same time. But they were not to block the activities of a company by holding and not proceeding with powers. There was also a standard maximum price of 8d. a unit. The specific power granted under the Act was to open the streets to lay cables. An undertaking could supply electricity without Parliamentary powers if its wires were all overhead. Overhead wires were

used in a few early cases, but this clearly was only possible for very small undertakings. By the middle of the eighties many people felt that the Act too much hindered the formation of Electricity Supply Companies and the purchase clause was amended to give 42 years operation before compulsory purchase was possible.

The 21 years purchase clause of the 1870 Tramways Act was also superseded. In the nineties the government was anxious to rejuvenate the agricultural areas. A Committee was set up to inquire into transport in rural areas and recommended light railways as a remedy. Thus in 1896 the Light Railways Act was passed. Again authority was given by the granting of a Provisional Order, but the Act was much more favourable to the operating company than the Tramway Act. Compulsory purchase was not at any specified time but by agreement between the local authority and the company proposing to operate the line, and it was to be at a price determined by arbitration. Tramways could not lay tracks within 9' 6" of the kerb if one third of the frontagers objected but light railways had only a centre line and limits of deviation set down. A Light Railway was assessed for rates at a quarter of the net annual value while Tramways were assessed at the full annual value. This Act was soon used by companies wishing to build electric tramways, and although initially hesitant, the Board of Trade very soon freely granted them the relevant powers. Between 1896 and 1914 two thirds of the lines built in the streets and private roads were Light Railways.

2. ibid., P 35.
The power companies and the underground railways were granted powers by private Act of Parliament. There were not enough of them for it to be worth while having the simpler system of Provisional Orders. Here there was no question of municipal operation. The Power Companies covered a large area, while municipal operation was thought of as being something for a utility entirely or almost entirely within the boundaries of the municipality. Corporations, with one exception, made no attempts to combine for electricity supply, and in any case they would not have seen the supply of power over a large area as one of their proper spheres of activity. They were acting for their ratepayers, to ensure for them reasonably cheap and adequate supply; they were not general entrepreneurs seeking a profitable return. The L.C.C. promoted no Bills to construct tube railways, but this was partly because the underground Acts were passed in the early nineties when the newly formed L.C.C. was only just beginning to find its feet.

In neither of these two cases was compulsory purchase seriously considered. The power schemes covered too wide an area for it to be sensible for the big towns, or in some cases even the County Councils to take over the undertakings. The County Councils, moreover, had no tradition of municipal trading. In the case of the Central London Railway, the L.C.C. certainly felt that it should have powers of future compulsory purchase, but the Select Committee on the Bill saw no reason why this should be so. The only control in these cases was the fixing of maximum

prices for the power companies and an insistence that the underground railway companies should provide an adequate number of cheap and convenient trains. Also schemes were to be carried out in a reasonable period of time. There was no unalterable time limit, where there was an initial limit, extensions of time were granted - and the best stimuli to starting on the scheme were the expectation of profit and the fear that otherwise a similar competing scheme would be authorised. In the case of the power companies no two competing schemes were authorised at the same time. Where two companies promoted Bills at the same time for similar areas only one was passed. As in the case of general electricity supply and tramways, the basic principle was the establishment of a formula which would stop the abuses of monopoly without further interference.

The initial conditions under which a company might operate an electrical utility were principally determined by Parliament. But the local authority had some influence over these conditions. In the case of undertakings set up by Private Act they could try and influence the final form of the Act, principally in Committee. In the case of the Power Company Acts, all the local authorities seemed to want to do was to get themselves excluded from the area of supply. This was on the general grounds that the power companies, who had no obligation to supply to all comers, would simply compete for profitable consumers, leaving the municipal undertaking to founder on the unprofitable ones. The result would be a rapacious private monopoly. The large municipalities were usually able to get themselves excluded, either in Committee, or by agreement. The latter meant that the power company agreed to exclude
them rather than risk losing the whole Bill because of local authority opposition. This was a curiously negative form of public utility control. Its tendency was to ensure profits were not excessive by keeping costs up.

In the case of the underground railways, the then newly formed L.C.C. wished to influence the original Acts. For example it wished to have the trains take the most direct route between stations and not simply follow the streets. It also wanted bigger tunnels and cheap workmen's trains. But although they could object to certain parts of the arrangements, they had no way of getting any positive suggestions adopted. For example, the Baker Street and Waterloo Railway proposed to run its tunnels under the streets. Anyone who looks at the street plan will see that this is awkward and generally undesirable, but the Railway wanted to avoid paying for wayleaves. The L.C.C. could, and did say that the layout was foolish, but they were in no position to persuade the Committee to make the promoters change the Bill failing the promotion of an L.C.C. Bill. All they could do was to raise some very thin objections to the effect that they might, at some unspecified time, want to put sewers 60 feet below the streets, although they had no intention of doing so at the moment.

They were able to block certain proposals in various private tube Bills, usually those which might lead to any private monopoly. This meant preventing co-operation, such as the joint ownership of several lines, or, to give a smaller instance, the building of a joint interchange

2. See P.212
station at Hammersmith by the London United Trains and the District Railway. The prevention of this type of co-operation however hindered the physical productivity of the transport system. Thus, as in the case of the power companies, the intervention of the local authorities kept profits down by keeping costs up.

In the case of utilities set up by Provisional Order there is a sharp contrast between electricity supply and tramways. In the case of the former, the local authority would be granted a Provisional Order in preference to a company if both applied at the same time, but it had no further influence on the matter. In the case of the latter it had considerable power, stemming from the local authority's position as Road Authority. Before a tramway company could operate it had to agree with the local authority over its share of the expenses of road repair and often on its fares. The local authorities were particularly anxious to improve transport for the working classes and usually insisted on special workmen's trams at very low fares. There was also bargaining over power supply in the cases where the local authority owned the public supply station. The frequency of service could be regulated by the local authority, although this seems to have been less often done. If the tramway was being promoted under the Light Railway Act, the company and the local authority had to negotiate the length of time which was to elapse before compulsory purchase. All these were devices intended to limit any possible exploitation of the consumer. The intention was that tramway companies should make only normal profits, and if this was not achieved by regulating their selling prices, it could be achieved by getting
special concessions for workmen, or a general contribution to the rates.

The advantage of giving these controlling powers to the local authorities was that they had excellent local knowledge of the potential profitability of the tramways, as much information as the promoters had and more than a government body would have had unless it had made detailed investigations all over the country. But this was more than offset by the intense political antagonism which usually existed between local authority and promoters. The local authorities generally considered that companies would exploit the public unless severe checks were put on them. When the companies were optimistic of future profitability this could lead to the local authority driving a bargain which in the event reduced profits to a subnormal level.

Unfortunately the whole attempt to control public utilities simply by fixing a variety of initial conditions was to attempt what was virtually impossible. Initial conditions could only control profits adequately if the latter could be accurately forecast; but the profits of major innovations are extremely difficult to predict. The promoters, who ought for their own benefit to have carefully studied a scheme, were often wrong about potential profitability, not only in the early 1880s, but to a lesser extent in all subsequent boom periods. E. Garke, the head of British Electric, scornful though he was of legislators, miscalculated badly about tramway profits in the years around 1900. His argument that the failure to get the expected level of profits was due to the legislation itself is flimsy, and, as he knew what the law was at the time, inadequate. Even if each particular case had been very carefully studied before the
details of the concession were decided upon, the chances of giving the company normal profits and no more would have been slim. Applying an arbitrary period of 21 or 42 years was less likely to succeed.

But very much more important was that there was a very inadequate mechanism to ensure low costs. This was particularly unfortunate in the case of electricity supply where techniques changed rapidly and costs fell with these changes. These changes in cost could have a much greater effect on prices than any change in profits. The only control mechanism was the introduction of competition. The early belief that competition 1 was the sole necessary regulator had been lost by 1850, but competition was still allowed its uses. Thus in 1839, in the midst of the great d.c.–a.c. controversy, Major Harindin of the Board of Trade recommended that consumers should be able to choose between these two systems. Thus for each of the central areas two distributors were authorised. Similarly several of the Power Company Acts contained what came to be known as the "Kiteon" Clause. This provided that power companies could give a direct supply to power users within an area already supplied by an authorised distributor without the latter’s consent if the Board of Trade thought such consent was being withheld "unreasonably". Roughly speaking the withholding of consent was unreasonable if the tariff offered the particular consumer by the authorised distributor was above the long run costs of the power company.

If anyone wished to apply large cost reducing innovations he could apply for powers to compete with existing companies who had earlier been granted monopoly powers. If Parliament thought the plans were likely to

1. W.A. Robson. op.cit. PP 306 – 308.
2. After Sir James Kiteon who sat as Chairman of the Select Committee of the Commons which dealt with many of the Power Bills in 1900 and 1901.
be carried out, and to reduce costs as claimed, it would be disposed to
grant the requisite authority. But in one way its hands were tied. It
had given existing undertakers limited powers under a bargain struck when
they sought their original franchise. These were already designed to
prevent exploitation of the public. Parliament was thus loth to remove
these powers unless those risking their money had received a fair
remuneration. It was particularly loth to do so when the existing
suppliers were large and powerful municipalities. Thus to some extent the
desire to control monopolies simply by initial conditions restricted
Parliament's future actions.

If the consumer stood to gain considerably from new suppliers,
Parliament would authorise them to compete with existing ones. But the
gain had to be large. It was not only the greater political power of the
big municipalities which enabled them to stay out of the Power Companies'
areas when smaller municipalities were included against their will. It was
also their lower costs—in 1900 - 1901 as low as those of the intending
power companies would have been. Also competition in situations of this
sort might involve a long and expensive battle. Thus intending competitors
exploiting new innovations would only compete if their costs were likely to
be very much lower than those of existing suppliers.

Only substantial cost differences would be able to defeat an
entrenched opponent. As far as regulation of their activities was
concerned, existing suppliers, to pursue a line of thought succinctly
put by Professor Hicks, could lead a moderately quiet life, but were likely
to be smoken if they actually went to sleep.
All the arguments used above suggest that in the case of private electrical utilities there was no good substitute for detailed and continuous control by some governmental, or public body. This Parliament had no desire to see, and it would have regarded government or public operation as worse than government or public control.

Municipal trams and electric supply seem to have worked very well until about 1900 - 05. At first the local government areas were larger than the minimum efficient areas of supply. Apart from London, where both local government and electrical utilities were poorly organised, in most places the local government boundaries did very well although there are cases like Manchester and Salford, Liverpool and Bootle where a unified utility would have been better. Electricity supply and trams were well run by the Corporations. No cost comparison with the Company undertakings is feasible as the type of area supplied was different. The absolute costs of the municipalities were lower, both their running costs and the interest they had to pay on borrowed money. But they had the densely populated areas, often had a relatively greater power load, had more demand diversity because of greater size and had a bigger tramway load. Thus their costs ought to have been lower. There is a substantial difference in performance between different Corporations which makes the


2. There are good figures of running costs but good figures of capital costs, accounting for about ½ total costs, are not available or obtainable. The complications in a cost comparison between companies and municipalitie are very great and the margin of error in the result great. It is unlikely that such an operation would produce results worth the great labour of carrying it out.
citing of particular causes easily misleading. Manchester Corporation was for example more up to date and enterprising than that of Glasgow. The population of Glasgow was larger and it was renowned as one of the leading centres of efficient municipal utility operations. Yet as Table 82 shows Manchester was off the mark quicker and towards the end of the period had exploited the potential power load much more.

Table 82.

Non traction KWh sold by Corporations of Manchester and Glasgow

<table>
<thead>
<tr>
<th>Year</th>
<th>Glasgow</th>
<th>Manchester</th>
</tr>
</thead>
<tbody>
<tr>
<td>1896</td>
<td>1.5</td>
<td>2.5</td>
</tr>
<tr>
<td>1900</td>
<td>6.8</td>
<td>7.8</td>
</tr>
<tr>
<td>1904</td>
<td>18.2</td>
<td>14.8</td>
</tr>
<tr>
<td>1908</td>
<td>34.5</td>
<td>37.2</td>
</tr>
<tr>
<td>1912</td>
<td>54.9</td>
<td>74.5</td>
</tr>
</tbody>
</table>

Source: Calculations from Garke's Manual.

It is easy to find instances of municipal stupidity, but no more difficult to find instances of company stupidity. No Corporation was as enterprising, well managed and low cost as N.E.S. Co., but the big ones were in general better than the other power companies, and the smaller ones usually better than the supply companies of the smaller towns.

After 1903 the position was much less happy. By then N.E.S. Co. had shown that there was a potentially larger power load and that the
elasticity of demand for electricity for power purposes was high. In that year Charles Merz demonstrated to Parliamentary Committees of both Houses that large scale supply would be much cheaper than supply by the existing small scale undertakings. From then until 1914 the success of N.E.S. Co. showed that the region was becoming the necessary unit for electricity supply. In the case of tramways, the position was somewhat similar. The urban areas had electric trams and the next step was to link those town with inter-urban lines, a step which was within the bounds of economic feasibility in the densely populated areas, like South East Lancashire and the Black Country.

One would not have expected any movement towards general government control under the Unionist government of 1896 - 1905. They had been quick to investigate the question of large scale generation and had appointed the Cross Committee in 1893. But their answer to the problem was to pass the Bills sought by the power companies in a modified form. They were not against municipal enterprise but Halevy has suggested that the reason why they were quite happy to encourage municipal socialism was that they regarded it as a safeguard against nationalisation.

In any case the problem was not pressing before 1905. But after that it was; from then onwards there can be no real doubt of the desirability of increasing the size of electrical utilities. But the government took no initiative at all. The Liberal government was more strongly in favour of municipal operation than its predecessor; for example in 1906 Merz's scheme for London's electricity was blocked until the L.C.C.

should produce a good plan of its own. But in general it was no good simply blocking Company schemes as the local government unit which was willing to run schemes had become too small. If big private schemes were to be disallowed there were two alternatives. One was to group together local authorities. As is suggested below they were not likely to group themselves on their own. The other was for the government to devise its own national or regional scheme. It did neither. This seems to have been partly a question of men and priorities. John Burns, the President of the Local Government Board from 1906 - 14 was a spent force by the time the Liberals came into power. Two of the foremost members of the government were at the Board of Trade, Lloyd George from 1906 - 08 and Churchill from 1908 - 10, but both were more interested in labour relations than in industrial organisation. The government was radical in its desire for social reform but not a supporter of government interference with the economy. They would have had to be persuaded of the need for the latter, and there was no strong body which could have convinced the government of public need. The realisation of the public need came only after the series of committees which sat during the 1924 - 28 war had revealed the weaknesses, particularly of electricity supply. The only pressure group was that centering around British Electric Traction. But it was principally concerned to argue for less government interference and control rather than more. It vehemently opposed municipal operation

1. There is only one case of co-operation, that of the Stalybridge, Hyde, Mossley and Dukinfield Tramways and Electricity Board.
and restrictive legislation. What it wanted was bigger and freer private monopolies. A case can be made out for them in the public interest, but there was little chance of persuading the Liberal Government of their desirability. Where the government did intervene, as in the case of London's electricity supply in 1906, it intervened to favour the London County Council against the vigorous private interests.

The municipalities did not co-operate with each other. The reasons are principally political, but not solely so. There were also the problems created by different tramway gauges, different frequencies, and voltages in electricity supply. Linkage of different networks would be expensive. This was particularly the case with tramways where it would involve relaying a great deal of track, but even in the case of electricity supply where cheaper expedients were possible, linkage still involved considerable capital expenditure if the economies of joint operation were to be realised. Unfortunately at the time when there were beginning to be advantages in such combinations, i.e. from about 1905, the capital market was turning against the local authorities. One must not over-estimate the difficulties presented by the different engineering characteristics of different town systems for there was a certain amount of standardisation. Most tramway gauges were 4 ft. 8½ ins., and electricity generating stations could have been linked up to considerable advantage without great cost. The latter would have reduced future investment to meet a growing demand as less plant would have been needed for any given load. A major obstacle to combination was that the Corporations were primarily concerned with their own citizens. In the
late 19th century they had undertaken a large amount of utility operations, water, gas, sewerage, as well as trams and electricity supply. Municipal trading had been a powerful movement sweeping away many laissez-faire ideas. It had aroused tremendous opposition and defeated it, but much of its force was spent by 1900. To expect them to pursue matters still further, and overcome all the obstacles to linking up electricity supply and trams throughout a region was perhaps too much. The experience of the Electricity Commissioners in the twenties is illuminating; they had great difficulty in co-ordinating the various suppliers.

To do so would have required joint action with the companies, who operated the areas between the big towns. No one could have expected the initiative for this to have come from the local authorities. For over 25 years they had regarded companies operating public utilities as potential exploiters of the community. Municipal trading had been strongly opposed by the business community, and this antagonism as well as hatred of monopoly had left its mark on the Corporations. Between 1905 and 1914 these attitudes mellowed, but only slowly. Some Corporations, for example Middlesborough, Stockton and Tynemouth began to take a bulk supply from N.E.S. Co. when their own plant became inadequate to meet the demand. The Lancashire Electric Power Company found that the initial antagonism of 1905 was passing away by 1910. In transport however the antagonism had been much greater. Parliament had given the local authorities powers to control company utilities or to operate their own. The control powers had been much disliked by the new electric tramway companies in the years around

1897 - 1903, especially British Electric Traction. They felt that the local authorities were driving a very hard bargain; and also that they used their powers to operate as a bargaining counter. Take for example the case of British Electric Traction and the Paisley & Johnstone Tramways. The former was to carry out a scheme of single track electric trams along the road between Johnstone & Paisley on behalf of the Paisley Tramways Company. At first they were given to understand by Paisley Corporation that permission would be granted for this. But Glasgow Corporation opposed the scheme, persuaded Paisley to join them and insist on a double line. This B.E.T. refused to build and as a result Paisley Corporation opposed their application for a light railway order. As a result the order was rejected although the Chairman of the relevant committee was moved to say that "we do not think that this Electric Traction Company has been dealt with in a fair and open way in this matter." Such violent antagonism might have been expected when one body was given power to control and to operate. Naturally this antagonism passed even more slowly than in the case of electricity supply. If it was too much to expect the Corporations to take the initiative, it was even less likely that they would have responded to any on the part of the power companies. What was required technically was a monopoly over a wide district and this was what the local authorities most feared. Concentration on large generating stations with abundant


2. C. Klapper, op.cit. gives other examples.
water supplies for cooling, easy coaling facilities and cheap land would in many cases involve putting them outside the boundaries of the large towns. Once deprived of their generating plant the municipalities felt they would be in a very poor position and would be exploited.

In this situation only the Government could be expected to overcome the difficulties. But it would have meant considerable effort on its part. For it was not a question of granting new powers to anyone, but of co-ordinating the operations of existing undertakers. Yet despite the fact that by 1905 it should have been becoming clear that the old policy was not working well, and that what was needed was not compromise but co-ordination, Parliament and the Government continued to be passive and permissive, rather than active and organising. This is shown by the Act of 1909. Much early legislation had been directed against the combination of utilities, as it was feared this might lead to monopoly. Parliament does however seem to have been willing to authorise the interconnection of different networks. The North Eastern power companies do not seem to have had any difficulty in getting Acts for this purpose, although considerable municipal opposition could have prevented interconnections. The Act of 1909 removed many of the obstacles to running joint systems both for companies and for local authorities. But to permit them to combine was not enough. To achieve any success the Government would have had to have taken a much more active role. No combinations of any importance resulted except in the North East.

The situation in London in both transport and electricity supply illustrates the difficulties caused by the government's attitude. In the
case of electricity supply the Unionist government fell before Merz's scheme passed its third reading. The Liberals relied on the L.C.C. but the latter soon became both unable and unwilling to carry out an overall scheme. Also the optimum area of supply was larger than the Administrative County of London. It would have needed a government body to impose agreement on the existing local authorities, the L.C.C. and the Boroughs, and on the existing company undertakers. A Royal Commission was appointed to inquire into London's Transport but despite the fact that it reported that "the present unsatisfactory conditions are largely due to the fact that there did not exist in the past any municipal or other authority having jurisdiction over the whole area and possessed of sufficient power and resources," no further action was taken. Here again the L.C.C. was unwilling and unable to shoulder the burden of a complete scheme. Combined with this it had an exaggerated fear that any private overall scheme would have all the dangers of a vast monopoly. This fear had led to its strenuous opposition to Merz's Bill in 1905, and it also led to opposition to any private attempts to link up London's traffic systems. Thus when the London United Trams proposed to build an underground tramway terminus at Hammermith, with direct contact with the District railway, this was opposed, successfully, by the L.C.C. on the grounds that it would help to create a monopoly. Yet it was lack of such a station at Shepherds Bush that caused great traffic congestion as passengers changed from the Central London Railway to the London United Trams. The Underground Railways Company had wanted to lease

the Baker St. and Waterloo and the Charing Cross and Hampstead Lines and link them up with a single fare and interchange. But their Bill was thrown out on the grounds that it would give too much monopolistic power, although both these lines were controlled by the Underground Company who held a majority of their shares. In this case the Parliament's utility policy led to the worst of both worlds. As the Royal Commission commented,

"The L.C.C. had no power to control the construction of (the underground) railways, and an attempt to exercise in the interests of the public such control as is possible by formal opposition to Private Bills does not give satisfactory results, while it adds to the cost of the undertaking, and tends to produce a state of antagonism between the Companies and the Council, which is greatly to be regretted and is detrimental to the public interest."2

1. ibid., Q 20202 ff Evidence of Charles T. Yerkes.
2. ibid., Report B.P.P. 1905, Vol. 50. P 573
Chapter 10.

The pricing policies of Electrical Utilities.

This chapter is primarily concerned with electricity supply, although towards the end there will be some discussion of trams and urban and suburban railways.

I

It was very soon noticed that in the production of electricity, as opposed to the production of most commodities, the rate of production at any particular time of the day is governed immediately and directly by the rate of demand at that time. The storage of electricity, by using batteries, although possible on d.c. circuits, was never attempted on a large enough scale to even out the rate of generation. No one was able to present a convincing argument to support any economic case for doing this; and no supply authorities tried to use batteries in this way.

The early lighting loads had a sharp peak in the early evening, while for the rest of the day demand was low. This light loading of plant most of the time soon worried engineers; they were quick to develop a measure of capital utilisation in the load factor, and to see the effect of the load factor on costs. What seems to have directed their attention to this is not that it was particularly low compared with that of a great deal of machinery, but that it was noticeably low. In the 1890s the annual load factor of electricity supply stations was 8 - 12%. If
normal industrial machinery was used continuously on an absolutely steady load for 9 hours a day in a 270 day working year its load factor would be only 20%. But in practice all machinery was used intermittently and with a varying load, and the usual load factor was not more than 15% - 20%. Power stations were necessarily open for 24 hours a day, seven days a week, and thus idle machinery was more obvious than in factories, which people expected to be closed on Sundays and usually at night.

It was also quickly seen that some form of discriminatory pricing could affect the electricity load factor, and thus costs in a way which was impossible in the case of the manufacture of other products. That is to say average costs, the cost per unit supplied, could be reduced. It was generally assumed, as far as one can see without any serious discussion, that this was a desirable objective. This is not so. What is desirable is to reduce costs for a particular service or commodity and there is no simple reason for supposing that simply evening out the load will do this. For example, inducing people to burn lights all day and all night would reduce the average cost of electricity, but would not reduce the cost of providing light when it was required. It can be argued that the best pricing system for electricity supply is a tariff which primarily discriminates between units used at different times of the day, where the price is determined by the long run marginal cost of providing current at that time. This implied a price at the peak hour sufficient to cover

1. This is all argued in I.M.D. Little, *The Price of Fuel*. 
capacity costs plus peak hour running costs, and at non peak hours sufficient to cover non peak hour running costs. Such price discrimination would improve the load factor but it does not follow that any attempt to do the latter will produce a “correct” allocation of resources. It might seem at first that a discriminatory pricing system which sought to improve the load factor would be one which moved in the direction of charging rates at peak and non peak hours which approximated more closely to costs than a uniform tariff, as non peak hour subsidisation was not likely. But as will be shown the tariffs used did not do this, and this was partly because the problem was seen first and foremost as one of improving the load, and not of charging economic costs.

This was strongly reinforced by the way in which the relation of cost and load was looked at, for this affected the type of tariff used. The classic statement on costs was made by John Hopkins in a paper to the Junior Engineering Society in November 1892. He suggested that costs could be divided into 2 categories, standing costs, that is the costs of being ready to supply current, and running costs, the cost of actually supplying it. Standing costs comprised the bulk of total costs; they were the capital costs of the equipment necessary to meet the maximum load on the supply station, the amount of coal which was used in warming up boilers and keeping up steam in readiness to supply electricity, and the bulk of the wages of the men employed. Having estimated the relative magnitude of these two types of cost he went on to consider how they should be divided among consumers. He concluded that customers should pay for running costs on the basis of the number of units used, and that standing costs should be divided among customers.

on the basis of the peak load which each demanded. Charging was thus to be based on the customers' load factor and only on the station load factor in so far as the peak demands of all customers coincided. They did not. The rationale behind this was that the supply undertaking had to be ready to give a rate of supply based on the total amounts which each consumer might demand. The actual situation envisaged was that all consumers might switch on their lamps in a fog. In London peak loads did coincide with fogs and this might seem to justify the argument. But what Hopkinson neglected was that the probability of the peak load occurring at any one time varied with the time of day, there being an extremely high probability that it would occur between 4 p.m. and 6 p.m. on a weekday in the winter months when commercial and domestic loads overlapped. From this it could be argued that customers ought to be charged a rate based on the standing costs multiplied by the probability of the maximum load occurring at that time of the day, plus the running costs. In practice the probability was extremely high that the maximum demand would occur during a period of some 2 or 3 hours.

Of these two charging systems the one accepted as both economically correct, and also equitable by most engineers, was one based on the consumers' load factor. Compared with a time of day tariff it had 2 major disadvantages. It could only affect the consumers' load factor, and not the timing of the consumers' peak. As consumer peaks varied it had much less effect on the load factor than a time of day tariff would have done. It failed to encourage off peak users like theatres, and perversely discouraged off peak users like churches who happened to use their lights for a short period of the week only. Allied to this, it did not go as far as a time of day tariff would have done in charging consumers
the cost of the resources which the community devoted to providing them with light at particular times of the day. It may have been an improvement on a flat rate, but a consideration of its application shows that it had other disadvantages which led to its being partially abandoned, only to be retained in a form which allowed considerable misallocation of resources.

At first electricity was charged for at a fixed price per KWh. There are a few instances in the early eighties of it being sold by contract, that is unmetered, the charge being based on the number of lamps, but by the time the boom of 1839 - 91 came meters were virtually universally adopted. Thus in the early nineties most electricity was sold at a flat rate in the way in which nearly all other goods and services are sold.

The first discriminatory tariff antedated Hopkinson's paper, being introduced by the Liverpool Electric Supply Company in 1888. There were three rates. For any number of KWh up to a hundred times the maximum demand of each consumer in KW, he was charged 1s. per KWh. Thus if the maximum load was 5 KW the first 500 KWh cost 1s. per KWh. Units from one to two hundred times the maximum demand cost 8d., and all subsequent ones 4d. The tariff was thus ideally directed towards the consumer's individual load factor, and not towards the power stations' load factor. However, there was no way of measuring the consumer's maximum demand and so charging was based on the consumer's possible maximum demand, measured by the number of lights he had installed. Few people liked the tariff. It was argued against it that it failed to encourage obvious off peak users like churches, workshops and other places
which might require light in the daytime. It was also said that the customers had difficulty in understanding the system. These disadvantages led to the system being abandoned four years later.

Hopkinson's paper of 1892 aroused great interest and was generally approved of in principle. Immediately following it, Arthur Wright, the electrical engineer to Brighton Corporation, wrote to the Electrician stating that he was engaged in starting such a system. He was to measure the maximum demand of the consumer by means of a thermal type maximum recording ammeter. The Wright demand indicator, as it came to be called, was to be set every month in the 2 winter quarters. It recorded slowly, taking about 10 minutes to reach the correct value. Hence the customer was not charged for peaks of very short duration. The mean of the 6 maxima was taken as the basis for charging. The consumer was to pay 7d. per unit for the first hour per day the demand had been used and then 3\(\frac{1}{2}\)d. for all subsequent units. In other words 7d. per KWh was the charge for \(\text{Max average demand in KW} \times \frac{365}{2}\) KWh. This tariff began in February 1893.

The price differential was not, Wright told the first convention of the Municipal Electrical Association, ideal. If charges had been based on costs they would have been 8\(\frac{1}{2}\)d. for the first hour and then 3d. But the Provisional order had fixed a maximum price of 7d. The fall of costs with

2. Elect. Vol. 30 P 221. 23 December 1892.
3. Analagous to a clinical thermometer.
technical improvements soon led to a lower "off peak" price while the standing charge remained at 7d. By 1897 the former was down to 1½d. and in 1898 fell to 1d.

Wright considered that this system had been responsible for the improvements in the load factor which took place from 1893 onwards.

Table 89

<table>
<thead>
<tr>
<th>Year</th>
<th>Load Factor %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1887</td>
<td>14.1</td>
</tr>
<tr>
<td>1888</td>
<td>11.7</td>
</tr>
<tr>
<td>1892</td>
<td>11.1</td>
</tr>
<tr>
<td>1893</td>
<td>11.4</td>
</tr>
<tr>
<td>1894</td>
<td>13.4</td>
</tr>
<tr>
<td>1895</td>
<td>13.4</td>
</tr>
<tr>
<td>1896</td>
<td>16.0</td>
</tr>
</tbody>
</table>

The load factor is based on the average of the maximum demands of the year in question and the previous year. This makes an allowance for the effect of the rate of growth in the load factor, which is not allowed for in the usual method of calculation.


His conclusion was supported. The Metropolitan Company asserted that their maximum demand type tariff helped to improve the load factor by discouraging the type of wealthy consumer who would connect five to six hundred lamps for ornamental purposes.

Wright preferred a tariff based on the maximum demand of each consumer to one based on the station peak load. He told the Municipal Electrical Association

"Theoretically, it might be said that the standing charges ought to be divided into amounts proportionate to the maximum demand of each consumer, at the day and at the very time the maximum demand occurred on the mains each year. This is obviously impossible to determine in practice, and would not be, moreover, necessarily equitable to the consumers who might or might not have used their maximum demands at the exact moment in question."

He thought his tariff gave "as nearly as possible the fairest division of the standing charges."

The Hopkinson-Wright tariff spread fairly quickly. By 1897, 29 of the 123 existing supply undertakings had adopted the Wright system with demand indicators. There were also variants on this incorporating the same principle. Often, as in the early case of Liverpool, the consumer's maximum demand was based on the number of lights installed. At Manchester C.H. Wordingham who had been one of Hopkinson's assistants and who was then in charge of the Manchester Corporation electrical supply station used a tariff with a standing charge of £12 p.a. per KW of maximum demand, and then 2d. a unit. The maximum demand was based on the number of lights installed. Wordingham would have preferred to use

Wright's system but the Corporation would not carry the consumer's account over for as long as a quarter. In 1893 the Metropolitan Electric Supply Co. was using a reduced charge for all units used above 8 per 35 watt lamp. These maximum demand systems increased in popularity during the late nineties and by 1904, 40% of all undertakings relied entirely on this form of tariff, while another 38% used it in conjunction with some other system. The remaining 22% were on a uniform flat rate tariff.

Thereafter the maximum demand tariff became the standard tariff for very big consumers. The Power Companies adopted it as the standard system for large consumers and bulk supply. But for smaller consumers it declined in popularity. From the beginning it had been under fire because it was said to be too complicated for the average consumer to understand. Also there was a constant stream of complaints from consumers about it. Not from all consumers, however; the Electrical Review noted in March 1899 that the opponents were often vocal and influential, while supporters generally kept quiet. In some places, Glasgow being one of them, the Wright system was so much disliked by consumers that the demand indicators were being taken out by the turn of the century. It was the shop keeper in the centre of the town who most disliked the system. He tended to use his lighting for only an hour or less per day in the winter evenings. Yet as W.A. Chamen, Glasgow's


electrical engineer, told the Municipal Electrical Association in 1901,
those were the heavily rated and influential consumers, who were quite able
to make their voices felt in the Council Chamber.

This consumer reaction was not all pressure group politics by
any means. For the quarterly bill could fluctuate quite widely if there
were variations in the number of lamps left simultaneously burning for
any quarter of an hour in the quarter. Thus it did produce considerable
uncertainly as to the amount of the bill unless consumers were extremely
careful to see that no more than a given number of lights were ever left
on simultaneously. Under the Wright tariff at Brighton any extra 60 watt
(16 candle power) lamp left on for a quarter of an hour in each month
would increase the quarter's bill by 2/9d. This would usually be a
noticeable proportion of the bill. In the nineties the lighting consumer
used about 500 units per year. If 200 units were used in each winter
quarter, the maximum simultaneous load was ten 16 c.p. lamps, and the
Wright system used with charges at 7d. and 1d. tje quarter's bill would be
£2. 4s. In this case each extra light left on would raise the bill
by 6%, although no more electricity was being used.

Such a tariff is more like a system of fines for exceeding some
stated amount than a way of charging for the extra costs incurred by the
supply authority. If the extra lights were not switched on at a period
of the station's peak no extra costs were involved. If on the other hand.

1. W.A. Chamen, Presidential Address to the Municipal Electrical
Association. Co.vent by Electrical Review in a leading article.

2. 0.6 kW x 91 days x 1 hour = 54.6 KWh @ 7d. = 382d.
200 = 55 KWh @ ld. = 285d.
527d.
it was generally at around a peak time that such extra lights were used. The probability that all consumers would do this on the same day was very low. Consumer choice is partially eliminated. Instead of being able to decide whether peak hour units were worth their cost, as the consumer would have been able to do under a time of day tariff, he was sharply penalised for exceeding some general limit, often when he would be unaware that he was doing so. Putting the matter rather extravagantly, it was as though there were something rather anti-social about switching on a large number of lights at any one time, like keeping library books for longer than the stipulated time.

Also it was often felt that the maximum demand tariff had only a slightly favourable effect on the load factor compared with that which would exist with flat rate charging. The matter was investigated in 1902 by C.A. Baker who collected figures of the load factor of all stations which had no tramway power load where such figures existed. He concluded that as the average load factor of stations using a flat rate was slightly better than that of those using a maximum demand tariff, the maximum demand system did not improve the load factor. His analysis was crude. The annual load factor as it uses a capital figure relating to December, is influenced by the rate of growth. However, plotting the load factor against the rate of growth for both types of tariff reveals that allowance for the rate of growth would not make any significant difference.

to the result. I have taken therefore those of Baker's figures where the rate of growth of demand was given, and as the following table shows, it is impossible to say that there is any significant difference between the load factors of stations on maximum demand and flat rate tariffs.

Table 90.

The effect of pricing on the load factor of a lighting station.

<table>
<thead>
<tr>
<th>Tariff</th>
<th>No. of stations</th>
<th>Average load factor</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flat rate</td>
<td>34</td>
<td>11.63</td>
<td>2.96</td>
</tr>
<tr>
<td>Maximum demand</td>
<td>49</td>
<td>11.35</td>
<td>2.28</td>
</tr>
</tbody>
</table>

The analysis is crude. Pairing stations similar except in respect to tariff might have produced a significant difference between tariffs. But it is very doubtful if enough information exists to do this now. On the other hand it may simply be that the load factor the light using consumer demanded was completely inelastic. In that case the use of a maximum demand tariff could have no effect on resource allocation or on average costs. This is not to argue that it would have no effect where electricity was used for power.

As a result of the complication and unpopularity of the Wright tariff, electricity supply undertakings began to modify the maximum demand principle. They more and more used the rough and ready way of assessing maximum demand by the number of lights fixed. Sometimes the tariff took the form of a rebate depending on the number of units used per lamp installed. In some cases it was modified still further by basing the
estimate of consumer's maximum demand on the rateable value of the house.

This latter method was pioneered at Norwich and by 1911 there were a number of other supply undertakings using it. During a discussion at the Institution of Electrical Engineers on a paper on Domestic Electricity Supply Tariffs in 1908, the President remarked that undertakings were drifting away from the maximum demand system towards simpler methods of charging such as were in vogue for almost every other commodity. The general trend of argument both in the paper and the discussion was towards a charging system based on the rateable value of the house or the number of lights connected. Such tariffs were simpler, consumers paid for $x$ units, $x$ being determined roughly by the size of their houses, at a high price, and the rest at a low price. If a demand indicator was used a fresh calculation had to be made to determine $x$ for each quarter's bill. But the former method was much less likely to achieve the desired result, which was to encourage consumers to raise their load factors. It became simply a rather arbitrary way of apportioning standing charges, with very little influence on resource allocation.

When electricity began to be used for traction and power purposes another type of tariff designed to improve the power stations' load factor was introduced. A specially low price was charged in cases where the load factor was known to be high. This type of charging had already been used in the nineties for street lights, which usually had a better load factor


than private lights. There were, however, few electric street lights.

Then the electric trams came at the end of the nineties supply undertakings were anxious to supply the power, for tramways had a 20 - 25% load factor. At first their attitude seems to have been to charge the highest price the tramways would pay. There are several possible reasons for this. One is simply that they thought the elasticity of demand for tramway power was low, another that they thought this and that the demand for electricity for lighting was elastic. They may simply have wanted to subsidise lighting at the expense of the trams, or most likely of all they simply thought that the addition of a high load factor consumer would reduce costs and thus lighting prices could be reduced. There is unfortunately very little direct evidence on intention, but the general feeling derived from reading many of the contemporary arguments is that they simply thought that a higher load factor would cheapen electricity by reducing costs.

Yet the tramways were in fact charged on a flat rate basis or on a sliding scale with discounts based simply on the quantity of electricity bought. However, it is not likely that they would have thought that the pattern of tramway demand could have been altered more than a very slight amount by the use of a maximum demand pricing system. They do not, however, seem to have discussed this.

In practice the demand for electricity from tramways turned out to be more elastic than supply authorities had at first thought, as the tramways either threatened to build their own power house to get a cheaper supply, or actually did so. Thus by 1900 the charge thought appropriate

1. There are a few cases of the use of the maximum demand system e.g. N.E.S. Co. and the N.E. Railway.
for tramways had fallen to about a third of the usual lighting price.

There were two ways in which the community could save resources by adding traction loads to lighting stations. One was because in some cases there were economies of scale to exploit, and the other was because in so far as the peaks of the two loads did not coincide less plant would be necessary than if a separate tramway power house was built. In practice the tramway load had morning and evening peaks and the latter overlapped with the lighting peak, and sometimes coincided with it. But in any case average cost was a misleading calculation to make. If pricing had been based on average costs, the tramways would have built their own power houses and any advantages of combination would have been sacrificed. In so far as this was done in the late nineties that is precisely what happened.

The threat of the separate power house led supply stations to charge tramways the average cost of traction kWh for a given tramway load factor. This is what they meant by charging the cost of supply, which was what the tramways tried to insist upon. Strictly speaking it was only the cost of traction power when the tramway peak demand coincided with the station peak. Thus competition forced the same effect as would have been obtained by a straightforward maximum demand system. Later this was made more explicit. In the few years before 1914 when power rates were lower than traction rates the tramways began to feel they were being exploited. Thus a joint committee of the Municipal Electrical Association and the Municipal Tramway Association was appointed to consider the price of energy

1. See Chapter 5 Section 4.
for traction. It reported in 1911 that the charge was to be based on cost. It divided costs into standing and running costs, and argued that tramways should pay a proportion of the standing charges of the power station determined by the ratio of the maximum demand for electricity for traction to the total maximum demand, plus running costs per unit used. This was thus a version of the maximum demand tariff.

The next important form of load was the power load. Industrial consumers often had quite a low load factor, but taken together it was higher owing to diversity, although there is unfortunately little precise information about the extent of this diversity. People turn lights on when it is dark, run trains when people cease work, but there is no similar reason why all intermittent power users should switch on together. The continuous power user had a high load factor in any case. Supply undertakings resolved to supply at a very low price to power consumers, partly because of their high load factor and partly because at first it was thought that the demand would be nearly all at off peak times. Both flat rate, with and without quantity discounts, and maximum demand systems were used, the first generally for the small power user and the second for the big ones. The use of a flat rate with quantity discounts in general led to lower rates for power, for the very big users of electricity, apart from the street lights, where discounts rarely applied, usually were the power users. This was not always so and thus this method of price discrimination was very crude.

Quite apart from this the costs of electric power compared with steam power was such that electricity would have to be sold at 1d. a unit before sales were large. In 1904-6 when the important power load was just beginning

1 Charges for Electrical Energy supplied for traction purposes from Combined Stations - Report of a Joint Committee of the Incorporated Municipal Electrical Association and the Municipal Tramway Commissioners
this was about a quarter of the usual lighting charge of 3½d - 4½d, and less than the usual tramway charge of 1d - 2d. It came to be accepted as the usual power price, although from 1908 - 10 onwards an even lower power price was thought appropriate.

There were suggestions that at a price of 1d. or less per KWh power was being supplied below cost. It is unfortunately impossible to bring adequate evidence to bear on this. The delivered cost of off peak units, including distribution costs could not have been more than 0.5d. per KWh, even in fairly high cost supply stations, by 1905. But power units were also used at peak hours, although even at the time very little seems to have been known about this. In 1909 it was argued by S.A. Russell that it was no longer economic to sell electric power at a "by product" price as it contributed substantially to the load. He went on to produce figures which were intended to show that power was often supplied below cost. These are not, however, convincing beyond reasonable doubt as they were done on the basis of individual consumers' load factors, plus an allowance for diversity of consumer peaks, and not in relation to the station peak. In the same year West Ham Corporation argued before the Local Government Board

1. (continued) issued 21st September 1911.


In Manchester in 1905 the average revenue from different classes of supply was:

<table>
<thead>
<tr>
<th>Class</th>
<th>Revenue</th>
</tr>
</thead>
<tbody>
<tr>
<td>Private lighting</td>
<td>3.86d</td>
</tr>
<tr>
<td>Public lighting</td>
<td>2.63d</td>
</tr>
<tr>
<td>Trams</td>
<td>1.49d</td>
</tr>
<tr>
<td>Motors</td>
<td>1.18d</td>
</tr>
</tbody>
</table>
that if capital costs were divided pro-rata amongst lighting and power customers power would cost 0.59d per KWh on the average. 5½ million KWh were being sold at an average price of less than 0.5d at the time. But capital costs ought to have been allocated to hours of peak supply and thus again the example is inadequate. There was a general feeling at the time that power supply was being subsidised, although there was usually no very clear idea of the crucial importance of the time pattern of the power load.

Where power was sold on a maximum demand system, the rates were often lower than for lighting on the same principle. This was to allow for the greater diversity of individual consumers’ power peaks. In this case and when power was sold at a flat rate, consumers using both power and lighting had to have two separate circuits, each with its own meter. The difference between lighting and power loads was arbitrarily determined in both cases, in ignorance of the time patterns of consumer demands and without any allowance for the different demand patterns of different consumers. This could cause considerable distortion in the allocation of resources, because big power consumers would install their generating plant as an alternative to taking public supply. In this situation accurate pricing based on cost is very important. As, however we do not know how close prices were to costs in the case of power supply no judgement can be offered on the possible extent of such distortions.

When electric cooking and heating seemed to be becoming commercially feasible in the last three or four years before 1914, supply for cooking was dealt with as for power, a special rate being levied which was to reflect the relative use of peak and off peak units. Rates were low.
by 191?, ten or twelve towns had a halfpenny cooking rate. It seemed as though the peak load was often scarcely affected. A.H. Seabrook, St. Marylebone's electrical engineer, asserted that a 1400 KW cooking and heating load had been added to his supply system in 1911 without affecting the peak load, which was 3740 KW.

The third main method of charging was that based on different rates for different times of the day. All the economic arguments are in favour of this type of pricing but it was surprisingly ignored in practice. It was not without its prominent advocates but the main body of opinion was opposed to it. Gisbert Kapp suggested a time of day tariff in the correspondence following Hopkinson's original paper on the cost of electricity supply. He proposed a clock which would adjust the meter at predetermined times. The best and most compelling arguments for a time of day tariff appeared in a series of articles in the Electrical Review in the second half of 1894 written by Alfred H. Gibbings, the Electrical Engineer to Hull Corporation. Stressing that costs varied with the time of day he argued for a tariff which should have the following characteristics:

1. i.e. the aggregate power of the apparatus connected.

2. During a discussion on a paper by F.H. Long to the Municipal Electrical Association on The Cooking Load from the Supply point of view.
   E.R. Vol. 70 PP 1034 - 6. 28 June 1912.


4. Alfred H. Gibbings. The Various Methods of Charging the Public for Electricity from a Central Station.
should know exactly what the price of using current would be. At all other times a low price would be charged based on the costs of off peak generation. The tariff should apply to all consumers, for whatever purpose supply was being used, and no rebates should be given to anyone. He argued quite correctly that the individual consumer's peak was not relevant to the ideal tariff.

Such a tariff needed a consumer's meter which adjusted automatically to allow for the time of day. He considered that Kapp's device was quite adequate for this. The latter was based on the principle of "shunting" the meter. It had an automatically rewound clockwork mechanism working a switch which adjusted the amount of current going through the meter, and hence the rate at which it recorded. The amount which went through at peak hours could be adjusted, which controlled the price differential between peak and off peak units. Such a meter really recorded in money rather than physical units. Such a device could be connected to any existing meter at a cost of about £3, thus being about half the cost of the meter itself. Some extra supervision was required but this would not add greatly to costs.

Gibbings considered that his ideal tariff was much simpler than maximum demand tariffs. He argued that much of the consumer objection to differential tariffs based on their maximum demands was the undeterminacy as to the final amount of the bill, which could be considerably affected by the height of the consumer's peak.

If adopted the time of day tariff would have been much simpler than the complicated set of tariffs which had grown up by 1914, with the
various versions and modifications of maximum demand tariffs and special prices for special loads.

This important series of articles provoked no editorial comments and no correspondence whatever. The tariff advocated was never given a reasonable trial. In Bristol a few houses had Kapp's "time switch" but only a few. In Norwich a time of day tariff was instituted, and the consumers' meters controlled from a clock at the Central Station. But in neither place did the tariff last.

There seem to have been two reasons. The first was the alleged unreliability of the clockwork time switch and the alleged high cost of the centrally controlled system. The second was that most supply engineers thought the time of day tariff mistaken theoretically. There is evidence that clock controlled meters were neither as reliable nor as cheap as Gibbins argued. In 1913 H.H. Perry, one of the foremost experts on meters, told the Manchester section of the Institution of Electrical Engineers that clock controlled meters had made little headway because of their high first cost, the need for monthly winding, the degree of skill needed for repairs and the prolonged period of testing required before they could be installed. Centrally controlled systems required a 3rd wire to the meter. They were thus said to be very expensive to install in existing networks, but in the middle nineties when most towns did not yet have electricity supply the extra cost of installing it in new networks would


2. E.R. Vol. 73, P 821. 21 November 1913.
have been much less. Also centrally controlled clocks do not seem to have been perfectly reliable in operation. However, time switches were being used, apparently with success, in seven towns in 1910, for special restricted hour tariffs. Also it is possible that the lack of interest of electricity supply engineers in the time of day tariffs slowed down possible improvement in these meters.

As has been noted Wright opposed the time of day tariff, and this view seems to have been held by most supply engineers. For example, W.A. Chamen, the Glasgow Corporation's Electrical Engineer, argued that "It does not seem to me to take a grip of the correct principle for it would result in charging a long hour consumer the additional price during part of twenty four hours for the simple reason that someone else wants to make use of the plant which is supplying him and makes him pay extra for the other consumer's shortcomings". In later papers on supply tariffs the time of day charge is usually ignored or very briefly dismissed.

Restricted hour tariffs were used and provide some approximation to a time of day tariff. It was used for electricity for motors, but appealed only to the small user who ran machinery intermittently. Well suited for fans, refrigerators, sausage machines etc., it could not be applied to factories where most of the demand existed. But with suitable loads it seemed to work quite well. First introduced at Burton on Trent in 1906 it produced a rapid rise in that town's load factor, from 12.7% to 19.6% in 1908 when power KWh sales had risen by 50%. There all but


10% of the motors connected were on a restricted hour basis. It was also used in Bradford, Dewsbury, Glasgow, Grimsby and Worcester where 11%, 53%, 7%, 26% and 19% respectively of the motors were on this tariff. Yet because of its lack of general applicability it was clearly inferior to a time of day tariff.

If the pricing situation which emerged to cope with the electricity peak was a little chaotic, that of the tramways and suburban railways was frankly perverse. In 1910 J.R. Salter in an important paper to the Tramway Congress pointed out that tramway costs could be divided between standing charges and operating costs as in the case of electricity supply, lamenting that the Hopkinson principle had not had full application to trams or railways. But not only was the Hopkinson principle not applied in that fares at peak hours were at the same rate as off peak fares, but they were often lower, because of workmen's tickets. The latter were disliked by the companies. For example, both the Great Eastern and the Central London Railways complained before the Royal Commission on London Traffic that they were unprofitable. Presumably they meant below average cost, but if this was so they would be far below long run marginal cost. It was Parliament and the local authorities who forced them to have them. The latter were particularly anxious to

have cheap workmen's transport, partly as a way to re-distribute income, but more as a method of trying to induce workers to leave the crowded unhealthy areas of the centres of the towns and move into the more salubrious outskirts. Naturally where they operated tramways themselves they usually had cheap workmen's tickets.

I have uncovered no evidence of tramway or railway companies desiring a higher peak hour fare although this would have more nearly allocated the costs of the services to those demanding them. It is however extremely unlikely that they would have been able to adopt such a fine structure. The municipalities would probably have regarded tramway companies as trying to exploit the public. The public would have felt the same of the railway companies; public opinion seems to have exercised an important regulatory function with respect to railway charges in general. It was particularly difficult to change from a flat rate to a time of day rate once the former had been generally adopted.

Once low fares at the peak hours were adopted competition between trams and suburban trains made it difficult for either to raise them because of the high elasticity of substitution between tram and suburban train travel. To do so, collusion would have been necessary and could hardly fail to have been noticed.
Chapter 11.

Some further comments.

The Electrical Industry is an important one in the British Economy during the period under consideration. It was said to be a key sector, and its allegedly slow growth is sometimes said to be one of the reasons for the slow growth of the economy at the time. Yet despite its slow growth it was an important component of total investment in Britain. The relevant figures from 1897 on are in Table 91. They understated the statistical importance of electricity in three ways. Firstly, all electric railways except the London Underground are excluded. Secondly, investment in wiring in the premises of consumers buying electricity for lighting and power is excluded. Thirdly, non-traction motors and lights are excluded.

The importance of the growth of the electrical industry in stimulating the growth of the economy cannot simply be measured by its share of capital formation. A consideration of the stimulating effect of electricity would, however, be rather complex and will not be attempted here. Two matters will be considered in this final chapter; firstly the pattern of innovation and how it was affected by economic factors, and secondly a sketch of the sources of finance.

I

Firstly we must look at the process of innovations. Innovations vary in importance. In this industry, where innovations were directed
Table 91.

Gross Investment in Fixed Capital in the Electrical Industry
1897 - 1913.

<table>
<thead>
<tr>
<th>Year</th>
<th>Electricity Supply</th>
<th>Electric Tramways</th>
<th>London Underground Railways</th>
<th>Isolated factory power plants</th>
<th>Total</th>
<th>Percentage of Gross Investment in the U.K. (Feinstein)</th>
</tr>
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<tbody>
<tr>
<td>1897</td>
<td>£m</td>
<td>£m</td>
<td>£m</td>
<td>£m</td>
<td>£m</td>
<td>3.1</td>
</tr>
<tr>
<td>98</td>
<td>2.47</td>
<td>0.57</td>
<td>0.81</td>
<td>0.15</td>
<td>4.00</td>
<td>3.8</td>
</tr>
<tr>
<td>99</td>
<td>3.29</td>
<td>1.68</td>
<td>0.93</td>
<td>0.15</td>
<td>6.05</td>
<td>5.4</td>
</tr>
<tr>
<td>1900</td>
<td>4.82</td>
<td>2.55</td>
<td>1.65</td>
<td>0.38</td>
<td>9.40</td>
<td>8.0</td>
</tr>
<tr>
<td>01</td>
<td>6.26</td>
<td>7.00</td>
<td>1.66</td>
<td>0.35</td>
<td>15.27</td>
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<td>6.78</td>
<td>5.54</td>
<td>1.73</td>
<td>21.65</td>
<td>11.3</td>
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<tr>
<td>04</td>
<td>5.24</td>
<td>6.22</td>
<td>6.65</td>
<td>1.88</td>
<td>19.99</td>
<td>10.8</td>
</tr>
<tr>
<td>05</td>
<td>5.36</td>
<td>5.90</td>
<td>5.40</td>
<td>2.27</td>
<td>18.93</td>
<td>10.9</td>
</tr>
<tr>
<td>06</td>
<td>4.58</td>
<td>5.91</td>
<td>3.82</td>
<td>3.01</td>
<td>17.32</td>
<td>10.6</td>
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<td>2.89</td>
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<tr>
<td>08</td>
<td>2.73</td>
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<td>0.46</td>
<td>2.34</td>
<td>8.35</td>
<td>7.0</td>
</tr>
<tr>
<td>09</td>
<td>2.60</td>
<td>2.92</td>
<td>0.35</td>
<td>5.21</td>
<td>11.08</td>
<td>9.2</td>
</tr>
<tr>
<td>1910</td>
<td>2.72</td>
<td>1.73</td>
<td>0.69</td>
<td>3.24</td>
<td>8.38</td>
<td>6.8</td>
</tr>
<tr>
<td>11</td>
<td>2.81</td>
<td>1.71</td>
<td>0.73</td>
<td>2.48</td>
<td>7.73</td>
<td>6.4</td>
</tr>
<tr>
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<td>1.93</td>
<td>1.90</td>
<td>3.30</td>
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</tr>
<tr>
<td>13</td>
<td>3.34</td>
<td>1.62</td>
<td>2.78</td>
<td>1.23</td>
<td>8.97</td>
<td>5.7</td>
</tr>
</tbody>
</table>

1. Converted to calendar year basis.

2. For method of calculation see Appendix P. The figures in this column are very crude.


Sources: Tables 16, 35, 46, 22 and 28.
towards cheapening some final product which was already in existence, for example, light, tramway transport and turning power, the importance of an innovation could plausibly be measured by the extent to which it reduced the cost of the final product (or products). There is unfortunately very little good information on costs, and what does exist can only measure general long run trends. Thus one must rely on impression. Reading the technical literature one is left with a strong impression that the size distribution of innovations was highly skew—a large number of small innovations, and a few big ones. Because of the lack of cost information one is only well informed about the important innovations. I shall attempt to generalise about innovation from the evidence about one end of the size distribution. This must, however, be done with care.

The rate of innovation is not only determined by economic factors, although they have been concentrated on here. However economic factors touch on the other factors. One important, largely non-economic determinant of the rate of innovation is the scientific possibility of advance. This is non-economic in that pure scientific research may by some discovery open up new fields. An example is the discovery of the principle of self excitation in 1867. But even pure science is connected with economic matters because the commercial use of something like electricity stimulates "pure" research, as well as research work directed to long range economic ends. In the electrical industry throughout the period 1875 - 1914 the

1. This is not to argue that, for example, electric lighting provided the same light as gas lighting. I have argued that there were quality differences. Nevertheless it provided a similar light.
possibilities of technical advance were high. This was particularly so in the 1880s and 1890s. But although there were few completely new developments in the years 1900-14, considerable progress was possible with existing basic types of equipment.

Another important determinant of the rate of innovation is men's ability to exploit the potentialities of technical progress. This is a function of education, and, what is an associated matter, the allocation of skilled manpower between various social needs. The educational system and the general social forces which help to direct able men into particular occupations will reflect the valuation which the society places on increasing the national income. But because we are talking of innovation and not invention, economic facts are important because skilled men with varying specific interests and ability can work in different frameworks. In the United States and Germany the electrical industry was much more centralised in the hands of a few big firms than in Britain. In Britain scientific research was carried out in Universities or by independent inventors. Although sometimes, like Parsons and Ferranti, they were engaged in development work often they were not. Users of electrical plant were separate from manufacturers of plant. There was little vertical or horizontal integration. Thus in Britain co-ordination was through the market place.

There are several groups of economic factors which must be discussed. Firstly, there is the existing factor endowment of the British economy at the time and the rate of growth of the British economy. Secondly, there is the effect of the degree of vertical integration within
the electrical industry. Thirdly, there is the degree of horizontal integration.

The effect of the factor endowment of the British economy on the rate of innovation is closely linked with the rate of growth of the economy. Because gas was cheap compared with the United States, electric lighting was established on a relatively small scale in Britain. Because the rate of urban growth was lower in Britain electric lighting spread less rapidly. Electric tramway development was hindered in Britain by factor endowment and the rate of growth of the economy (or particularly of certain sectors of the economy). There was little house building between 1890 and 1895 and after 1904. After the first wave of electric tramway building (1897 - 1904) the existence of a dense network of steam railways delayed or prevented the building of inter-urban tramways. At the same time it was often not worth electrifying short distance steam railways, even though, if there had been no trains, transport would have been most cheaply provided by a light electric railway (or inter-urban tramway). The growth of factory electrification was also held up by the slow growth of the economy. The growth of lighting power and traction was slower in Britain than in the United States because of the relative scarcity of cheap water power. Electro chemistry developed little in this country principally for this reason. Comparative cost considerations ruled against any English Niagara Falls electric power scheme.

In the cases of electric lighting, power and traction reasons for the slow growth of electrical methods have been given in the relevant chapters. What is to be considered here is the effect of this slow growth
on innovation. In the 1880s, (more strictly 1879 - 91), when electric lighting seemed to have failed at the "take off" point, there was considerable innovation in Britain. Many inventions and improvements were made. Naturally they were not widely applied, but they were applied, and thus count as innovation and not simply invention. British engineers were quick to follow innovations made abroad. Crompton quickly followed Brush's lead in developing multi-aro dynamos. Swan invented the electric incandescent light bulb at the same time as Edison, and even though he did not, as did Edison, design a whole system of central station lighting, he and Crompton co-operated to produce the same innovations. Edison was in front of them, but not very far in front. In the case of the a.c. transformer and the use of high voltage transmission Ferranti in Britain saw the economic advantages of the transformer as quickly as anyone. His achievement was as great as that of William Stanley in the United States. Crompton and Willans developed high speed steam dynamos, an improvement on the small belt or rope driven dynamos used in other countries in the 1880s. Ferranti was the principal pioneer of paper insulated cables. Parsons developed the turbo generator. In small as well as in major matters there was great progress in innovation in the electrical industry when the economic situation was very discouraging.

The 1890s, (more strictly 1892 - 99) show an almost diametrically opposed set of conditions. The electrical industry began to develop fairly rapidly, especially after 1895, and yet the rate of innovation at home fell away to a very low level. The important developments in traction and power came from the United States and the Continent. A very slow rate of innovation was particularly marked among British manufacturers of

electrical machinery.

It would be odd to argue that a slow growth of the application of electrical methods stimulated innovation. On the other hand it is easy to see how lack of commercial success could deter further invention and innovation. Thus the evidence seems a little perverse. However we must distinguish between the making of innovations and the application of innovation. The rise of electric traction in the late nineties was the application of an innovation - or a series of innovations - made abroad. Thus one reason why the rise in demand for transport did not stimulate innovation at home was that the important innovations had already been made.

Also there seems to have been a considerable time lag in the response of innovation to economic conditions. The slow innovation of home manufacturers in the nineties is partly a response to the economic difficulties of the eighties. Because the financial return to innovation had been low in the eighties both lenders and the commercial directors of electrical firms became reluctant to finance and encourage it. This attitude is shown particularly clearly in the case of the electrical machinery manufacturers in the years 1896 - 1902.

After 1903 the slow growth of the market does seem to have had the effect of dampening down innovation. The slow rate of growth of demand for capacity in electricity supply delayed the adoption of some of the possible economies of scale in electricity generation. Yet a slow rate of growth of demand for capacity is clearly not necessarily a barrier to innovation. The experience of N.E.S. Co. shows how successful innovation
could nevertheless lend to a considerable growth in capacity. The financial difficulties of the years 1901-10 do seem to have reduced the development work undertaken by British manufacturers.

The second important economic matter to consider is the effect of the degree of vertical integration. The small amount of vertical integration in Britain compared with the United States and Germany produced a structure of the market for electrical plant that was said by contemporaries to be a handicap. Because electrical utilities and electrical manufacturers were separate and independent the consulting engineer was used to bring the two together. The consulting engineer laid down specifications—usually rather strict ones—for the equipment required. Manufacturers responded with tenders. In the United States by contrast the relations between plant manufacturers and utility were close, and utilities often simply ordered plant automatically from one manufacturer. In Germany the situation was much the same as in the United States. The same financial groups had interests both in utilities and manufacturers.

Contemporaries in Britain argued that the British system hindered progress. Much of the evidence does seem to be on their side. Standardisation was more likely to occur when manufacturers had more say in the type of plant they were to supply. Of course standardisation by itself was not necessarily an advantage; it could involve stagnation in design. The consulting engineer could stimulate manufacturers. In 1892 the Electrician argued that "perhaps nothing else has done so much to develop and improve the d.c. dynamo as the stringent conditions as to weight, size and heating which have been laid down in the Admiralty specifications." Yet in Britain there was certainly too little
This does seem to have kept costs up rather than down. By how much we cannot say; one must be careful not to exaggerate the possibilities of standardisation. Inevitably most plant had to be designed for a particular job.

More important than the question of standardisation, seems to be the possibility of developing plant by close co-operation between consumer and manufacturer, that is by continuing development work when the plant was actually operating. In Britain the use of a consulting engineer, with the system of rigid specifications and heavy penalties for not meeting guarantees does seem to have made close co-operation between manufacturers and utilities difficult. The fact that many utilities were local authorities made for further estrangement.

This view is supported by the facts that on the North East Coast there was close co-operation between manufacturers and N.E.S. Co. and that this seems to have had beneficial results. N.E.S. Co. had a purchasing policy quite different from that of other supply undertakings. Men often invited tenders on very open specifications for individual items of plant or merely consulted firms who he thought could build the machinery. Prices were often fixed by bargaining. If, after plant was installed, difficulties were experienced, the manufacturer would be called in. Where progress consisted in a series of small improvements made because operating conditions revealed snags this was very fruitful. For example a good deal of the improvement of metal clad switchgear was due to the close and friendly relations between Reyrolle & Co. and N.E.S. Co. The former had based their initial designs on the A.E.G. switches installed in Northumberland
in 1902. Many of the Reyrolle improvements were small changes after particular snags occurred in working. The problems were mechanical rather than electrical, and difficult to predict theoretically. Oil filled boxes burst when faults occurred; they were replaced with stronger boxes. On such matters, Mars & McLellan, the consulting engineers, N.E.S. Co. the operators of the system, and Reyrolle & Co. the manufacturers and contractors for switchgear co-operated closely, often on Reyrolle's shop floor. It was not a question, as with other supply undertakings, of collecting penalties and turning to other contractors. There was similar close co-operation between N.E.S. Co. and Parsons. It was at the Blaydon Waste heat & power station that Parsons made his first re-heating experiments with turbines. The low capital costs of the N.E.S. Co. system suggest that no penalty in terms of high prices was paid for this reduction in competition.

There are degrees of vertical integration. Integration means replacing a market structure with an administrative structure. Without arguing that complete vertical integration was desirable one can argue that too much reliance was put on a market structure, which did not have the necessary flexibility.

It can also be argued that there was too little horizontal integration. It has been argued in Chapter 9 that public utility control of the time led to insufficient horizontal integration in electricity supply and electric tramways. It may be asked whether the private monopoly which this control was designed to prevent - or at least strictly control - would have been more efficient. In the United States
as the minimum efficient unit in electricity supply expanded, holding companies were formed which controlled several local companies. In the 1920s private consolidation proceeded particularly rapidly. Electricity supply after 1905 is a clear case where if private monopoly had been allowed prices might have been lower as lower costs, because of economies of scale, might have overcompensated for higher profits. The crucial questions are the extent of scale economies and the elasticity of demand for electricity. The scale economies were quite large as the low costs of N.E.S. Co. show. There is no information which would enable us to make any precise calculations about the elasticity of demand for electricity. Nevertheless one can try and make some rough guesses based on literary evidence. For electric lighting demand was probably generally rather inelastic. It was certainly highly inelastic in the eighties when electric lighting was much more expensive than gas lighting. The elasticity of demand for lighting for lighting rose during the nineties as electric lighting costs came down towards gas lighting costs. Also in the late nineties the elasticity of demand for electricity for traction seems to have been quite high as tramway electrification proceeded rapidly. However, it was easy to practice price discrimination. After 1900 the elasticity of demand for electric lighting must have declined again with the introduction of the incandescent gas lamp. But the introduction


2. Chapters 3 & 4. The low cost of N.E.S. Co. electricity was due to other things than scale economies. But scale economies were important
of the metal filament lamp in the years 1908 - 10 raised the elasticity of demand for electricity considerably. The demand for electricity for power seems to have been quite elastic. The higher the elasticity of demand for a product the less we need to fear monopolistic pricing. In these terms therefore a case could be made out for regional private monopolies in electricity supply from 1905 to 1914 (and perhaps later).

In the case of electric tramways and the London Underground there were certainly economies of scale. There were not scale economies in an isolated large town but in conurbations where there were several operators. The economies of scale were economies of through running and would have reduced travel time rather than fares. It is very difficult to guess at the elasticity of demand for tramway and urban railway transport. It was probably higher in London than elsewhere. The general used contemporary index of travel frequency - journeys p.a. per head of population - was remarkably low in London, not only compared with very large cities but with big British towns. Generally, however, the demand situation for suburban housing does not lead one to expect a high elasticity of demand for urban and suburban transport. Hence the arguments for private monopoly are considerably weaker, both on the demand and on the cost side than in the case of electricity supply. London, however, is an important exception.

It is also possible to argue that more horizontal integration would have been desirable in the case of the electrical manufacturers.

1. While at the same time causing a once for all shift of the demand curve to the left.

2. Chapter 5 P 190.
In the United States and Germany high concentration went hand in hand with rapid technical progress. In 1902, with the formation of General Electric, electrical machinery manufacture in the United States became a duopoly. In Germany in 1903, the amalgamations of A.E.G. and the Union Co. and Siemens and Schuckert led quickly to a duopoly situation. The consequent reduction in competition does not seem to have led to any stagnation. On the other hand it does not seem to have led to any quickening of technical progress. However it might have done in Britain, although there is not enough evidence to be sure of the matter. British firms seem to have been big enough to exploit economies of scale. The manufacturing techniques used in building electrical machinery were not ones where these economies were considerable. Electrical manufacturers did scarcely any research before 1914. There do not appear to have been economies of scale in development work which British manufacturers could not benefit from. Yet it can be argued that the type of price cutting which resulted from the existence of 4 - 5 large firms in Britain did slow up innovation by reducing profits and causing illiquidity.

It may well be asked why greater concentration did not take place in Britain in electrical machinery manufacture. Not enough is known about the individual firms concerned to give an adequate answer. But the character of the recessions does provide a partial answer. It is significant that in Germany the amalgamations of A.E.G. and the Union Co. and Siemens and Schuckert were eased by the difficulties of the Union and

1. See Chapters 7 and 8.
Schuckert Companies. The relative gentleness of the English cycle in electrical equipment may have been disadvantageous. The more violent recessions in the United States and Germany even if they did not materially aid amalgamation, at least increased concentration by eliminating the weaker firms.

The electrical industry suffered from insufficient horizontal integration in that engineers and business men did not work well together. In the United States and Germany the major manufacturing firms employed many of the best electrical engineers. In Britain this was largely the case in the 1890s but in the nineties the major firms lost many of their engineers. However it is clear that mere amalgamation could not cure this; the gap between engineers and business men was too big. In any situation there is an inevitable gap between the two, but it does seem to have been particularly wide in Britain. Business men had virtually no technical training; engineers did not feel that commercial matters were their province. Indeed they were not encouraged to concern themselves with the firm's accounts. First rate engineers like Parker, Ferranti and Parsons felt that they must work on their own. Yet even Parsons might have done better if he had had greater business skill. This gap made it difficult for English firms to digest outside inventions. This is shown by the situation in the early eighties and the difficulties English firms had in building Parsons turbines.

1. Cf. D.W. Robertson, op.cit. pp 27 - 8. "Thanks to its more moderate and controlled expansion, the English electrical industry escaped altogether the catastrophe that befell its German neighbour."

2. See H.C. Passer, op.cit. for the United States.

3. Sir Alfred Yarrow commented that Parsons was a "stupid sort of chap in business." R. Appleyard. op.cit. pp 269 - 70. For comments on Ferranti see pp 366 - 7.
The rewards of an engineer working for an electrical manufacturing firm or an electrical utility were fairly small, unless he were a Director. Salaries appear to have been fairly low. There is very little evidence on this and it is difficult to make a balanced judgement. But there was constant complaint in the correspondence columns of the Electrical Review and the Electrician that municipal electricity supply undertakings and municipal tramways paid excessively low salaries, and that this led to their getting inferior men. There seems to have been a good deal of justice in this view, although one can point to very good electrical engineers who worked for municipalities. Low salaries may have led to employing men with a pedestrian approach to matters when what was needed (at least after 1905) was to persuade Town Councils of the need for co-operation with adjacent operators.

London transport seems to have suffered from a rather uninspired tramway manager, who was reluctant to make through running agreements with other operators.

In electrical machinery manufacturing engineers were also not, it seems, well paid. Nor were they given much scope for developing new designs of machinery. Many of them were attracted into becoming consulting engineers. There, as far as we can tell financial rewards were better, and there was also more scope in designing plant. It is

1. e.g. J.F.C. Snell and C.H. Wordingham.
2. See Chapter 9.
3. Charles Klayper. op.cit. p 246
likely, however that socially they had too much scope. Consulting engineers were not intimately connected either with the manufacture or with the running of plant. They were able to try out all their new ideas, which were often no doubt good ones, without worrying about the cost of production of electrical machinery generally, as opposed to the cost of a particular order. To reduce costs by standardising they would all have had to have acted, if not altogether, at least in groups. Given a situation of no standardisation, introducing special modifications is often justified.

In considering innovation the question of patents has been ignored. This has been done because there seems little to say about patents in electrical machinery manufacture, and nothing to say about patents in electricity supply and electric traction. This is partly because many products were developed abroad and introduced by new companies holding the English patent rights. But even without patent protection entry would have taken place because of a superior product which could not quickly be copied at existing prices. The rather scanty evidence suggests that it was not usually difficult to get licences to work particular patents. Again evidence is inadequate but royalties do not seem to have been high enough to restrict competition substantially. A subsidiary effect of the patent laws was to encourage overcapitalisation - patents being overvalued assets. But this is more an illustration of the poor understanding between technical and commercial personnel, and the speculative nature of the market for ordinary shares.

2. The evidence of firms' costs which might enable one to decide this question seems to have been destroyed - if it ever existed. Costing was primitive.
than a comment on the economic effect of patents. One must conclude this paragraph by saying that patents were very important in incandescent lamps, and led to a monopoly from 1888 to 1893.

Various comments have been made about financing in earlier chapters. An adequate study of financing would involve further research. But some general comments can be made. Most of the borrowing for electricity supply was done by the municipalities. Much of the money must have been subscribed locally, how much we do not know. Electricity supply companies were, it seems, largely financed locally. The directors were often local men. However there were also several national groups. British Electric Traction had considerable interest in electricity supply. This was usually in the areas served by the power companies. B.E.T. was the original owner of the County of Durham Power Co., and held several Provisional Orders for lighting and tramways in County Durham. It controlled the North Metropolitan Power Co. and held many Provisional Orders in the power company's area.

Edmundson's Electricity Corporation was a financial group with interests in small central stations in a number of small towns spread all over the country. Although it had helped to finance many electricity supply undertakings, as Table 92 shows, the total amount of money provided in this way was relatively small. The Edmundson's money was probably
Table 92.
Edmundsons Electricity Corporation Investments in and advances to Subsidiary Cos, March 1906.

<table>
<thead>
<tr>
<th>Company</th>
<th>£</th>
<th>As a percentage of capital expenditure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alderley and Wilmslow</td>
<td>40,608</td>
<td>92</td>
</tr>
<tr>
<td>Bromley</td>
<td>25,100</td>
<td>19</td>
</tr>
<tr>
<td>Folkestone</td>
<td>13,475</td>
<td>8</td>
</tr>
<tr>
<td>Isle of Wight</td>
<td>169,174</td>
<td>71</td>
</tr>
<tr>
<td>Ilfracombe</td>
<td>35,345</td>
<td>120</td>
</tr>
<tr>
<td>Lymington</td>
<td>30,939</td>
<td>88</td>
</tr>
<tr>
<td>Melton Mowbray</td>
<td>36,910</td>
<td>91</td>
</tr>
<tr>
<td>Newmarket</td>
<td>33,650</td>
<td>36</td>
</tr>
<tr>
<td>North of Scotland Co. (Brechin, Inverness and Montrose)</td>
<td>97,906</td>
<td>98</td>
</tr>
<tr>
<td>Ramsgate</td>
<td>34,103</td>
<td>97</td>
</tr>
<tr>
<td>Scarborough Trams</td>
<td>97,931</td>
<td></td>
</tr>
<tr>
<td>Salisbury</td>
<td>49,840</td>
<td>72</td>
</tr>
<tr>
<td>Urban R.S. Co.</td>
<td>409,789</td>
<td>53</td>
</tr>
<tr>
<td>(Cambourne, Redruth, Glossop, Twickenham, Hawich, Grantham, Berwick, Godalming, Newton Abbot, Stamford, Dartmouth, Weybridge, Newbury, Caterham)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Winchester</td>
<td>25,815</td>
<td>30</td>
</tr>
<tr>
<td>Wycombe</td>
<td>87,545</td>
<td>90</td>
</tr>
<tr>
<td>Lancashire Power Construction Co.</td>
<td>79,010</td>
<td></td>
</tr>
</tbody>
</table>

Also Investments in Guernsey (131,796) and in Cromer, Dorking, Frome, Hamilton and Surbiton (32,274)

Total £1,413,101

Total capital expenditure on electricity supply in Britain at the time was ... ... £59,440,222

largely raised nationally and used to supplement the money raised locally. Table 92 also shows Edmundsons lending to the undertakings they controlled as a percentage of the capital expenditure of those undertakings.

There were also smaller groups, for example the Electricity Supply Corporation and the Northern Counties Electricity Supply Corporations. They, like Edmundsons financed small undertakings in small towns.

Even quite big undertakings raised a large part of their capital locally. For example, N.E.S. Co. did not make any public issue outside the North East until 1906. By then it had spent £1,383,965 on capital account.

Although the matter has not been fully investigated it does seem that electricity supply undertakings found it difficult to borrow outside their locality. The power companies (except N.E.S. Co.) found borrowing difficult and yet other electricity supply undertakings seem to have been able to extend their plant to meet demand without difficulty. Because the power companies were not based on any one town they had no natural local source of money. N.E.S. Co., the one power company which was able to borrow fairly easily, supports this argument, for alone of the power companies it grew out of a local undertaking.

The finance of electric tramways was similar to that of electricity supply in that the municipalities were the principal borrowers. But the private sector was dominated by B.E.T. However we do not know where B.E.T. sold its shares. The London Underground

1. This percentage is not quite the right one to take. But it has been simple to calculate as I have been able to use my collected capital expenditure figures.
Railways were largely financed from the U.S., although the Yerkes - Speyer group must have borrowed heavily in London as well. To disentangle the financial arrangements in this case is a task on its own. The capital for the Liverpool Overhead Railway was raised entirely in Liverpool, and with great ease. The Mersey railway borrowed from Westinghouse for its electrification and the main line steam railways no doubt used their usual sources of money.

Electrical machinery manufacturers suffered more than the other sections of the industry from borrowing difficulties. This matter has already been partially discussed in Chapters 7 & 8. British financial companies did not usually sell many ordinary shares. Many of them were held by the Directors. Some of the Directors were often members of the original partnership or purchasers of the original patents, or the original inventors. Sometimes a local landowner, who had bought many shares, sat on the Board. Preference shares were held more widely but were not easy to sell except in times of considerable boom. Debentures were presumably more widely held still. Electrical machinery manufacturers also had heavy bank overdrafts and sometimes the Directors had to tide a company over a bad time out of their own pockets.

Over a period of nearly 40 years from 1875 - 1914 conditions naturally changed. But the underlying pattern described above does not seem to have altered much. In the years 1879 - 82 money was very easy to raise. From 1883 - 87 it was very tight. Then from 1898 right through until 1904 borrowing was not very difficult except for the machinery manufacturers. In the recession 1892 - 95 private borrowing
was not easy, but the municipalities were able to raise what they required. After 1904 interest rates rose, which could be a serious matter in a capital intensive industry working on small margins (e.g. electric traction and electricity supply). In the case of the L.C.C. capital market difficulties were an important cause of the scaling down of public utility schemes. London is, however, probably not typical. If the other local authorities had similar borrowing difficulties they kept rather quiet about them.

APPENDIX. METHOD OF CALCULATING VARIOUS TABLES.

Gross Investment in Electricity Supply.

Table 13.

Before 1895 capital expenditure figures are rather dubious. The Electrician made estimates for capital expenditure at the end of 1894, 5 & 6. I have also made estimates by the method described on Pages 486 - 8.

<table>
<thead>
<tr>
<th></th>
<th>Electrician £000</th>
<th>Mine £000</th>
</tr>
</thead>
<tbody>
<tr>
<td>1894</td>
<td>7,400</td>
<td>7,150</td>
</tr>
<tr>
<td>95</td>
<td>8,002</td>
<td>8,574</td>
</tr>
<tr>
<td>96</td>
<td>9,673</td>
<td>10,547</td>
</tr>
</tbody>
</table>

At the end of 1891 8 London Companies had spent £2,018,997. I have allowed another £1m. to cover other companies at the end of 1891. I have assumed that capital expenditure at the end of 1888 was only £300,000. I then interpolated graphically between these points and the later estimates made by the Electrician and me.

Gross investment was taken as the investment in capital expenditure.

Gross investment £m.

<table>
<thead>
<tr>
<th></th>
<th>Electrician estimates</th>
<th>Using my estimates</th>
</tr>
</thead>
<tbody>
<tr>
<td>1889</td>
<td>0.7</td>
<td></td>
</tr>
<tr>
<td>1890</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>91</td>
<td>1.2</td>
<td></td>
</tr>
<tr>
<td>92</td>
<td>1.5</td>
<td>1.3</td>
</tr>
<tr>
<td>93</td>
<td>1.5</td>
<td>1.3</td>
</tr>
<tr>
<td>94</td>
<td>1.6</td>
<td>1.6</td>
</tr>
<tr>
<td>95</td>
<td>1.4</td>
<td>1.4</td>
</tr>
</tbody>
</table>
Electricity supply undertakings had, under the Electric Lighting Acts, to make returns to the Board of Trade. However these returns were only published for 1899 and 1900, and in some respects are incomplete. A search for other returns in various Government departments and at the Public Record Office has proved fruitless. Thus I have had to fall back on the figures in Garke's Manual. Data on capital expenditure are given for most undertakings for most years. There are some gaps. Also something was spent on Capital account before the undertaking was opened, and often the amounts are unknown. Estimates were made for missing years by linear interpolation. To allow for capital expenditure before the station opened it has been assumed in most cases that capital expenditure was zero at the end of the 3rd year before that in which supply began. In the cases where the undertaking was small and capital expenditure was £20,000 at the end of the year in which supply began it was assumed capital expenditure was zero at the end of the 2nd year before that in which supply began.

The magnitude of errors in estimation depends on the size of the undertakings for which figures are missing and the size of the gap between known figures for undertakings. Happily there are only short gaps for the big undertakings. Often it is only one year and an estimate which is the arithmetic average of capital expenditure in the previous and following year cannot be far out. The undertakings with very long gaps or very unsatisfactory figures are the small ones. For a few of them, capital expenditure figures have been estimated from figures of issued capital.
In order to get some idea of the possible errors which might be involved in estimation those undertakings with long gaps in their published figures were put into a separate group. This was done when there were estimates more than \( \frac{3}{\pi} \) consecutive years. However the period was not treated as a whole as on several occasions a good run of figures contains a gap at one end. The period was divided into two parts, 1895 to 1904 and 1905 to 1914 inclusive. Care was taken to see that long gaps in the period 1902 to 07 were not ignored. Where a run of figures for one of the two sets of years had more than 2 estimates linking on to a set of more than 4 consecutive estimates in the whole period 1902 to 07 it was put into the separate group.

Sometimes published figures were rather uncertain. Where this occurred they were assumed to be rather more reliable estimates of the truth than are possible if no figures at all exist for a year. If the figures of an undertaking contained estimates plus uncertain figures for one more consecutive year than simply where estimates alone were considered, it was put into the separate group.

The aggregate capital expenditure in the separate (more uncertain) group is below expressed as a percentage of aggregate estimated capital expenditure (more certain plus uncertain group).

<table>
<thead>
<tr>
<th>Year</th>
<th>1895</th>
<th>1896</th>
<th>1897</th>
<th>1898</th>
<th>1899</th>
<th>1900</th>
<th>1901</th>
<th>1902</th>
<th>1903</th>
<th>1904</th>
<th>1905</th>
<th>1906</th>
<th>1907</th>
<th>1908</th>
<th>1909</th>
<th>1910</th>
<th>1911</th>
<th>1912</th>
<th>1913</th>
<th>1914</th>
</tr>
</thead>
<tbody>
<tr>
<td>%</td>
<td>2.4</td>
<td>2.8</td>
<td>3.2</td>
<td>3.7</td>
<td>4.1</td>
<td>4.3</td>
<td>4.9</td>
<td>5.3</td>
<td>6.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
</tr>
</tbody>
</table>
The errors can scarcely be higher than these percentages. Errors in the capital expenditure figures would be serially correlated and thus errors in the gross investment should be no larger than in capital expenditure.

Depreciation normally took the form of a sinking fund. Where it did not I have corrected the relevant capital expenditure figures. Where plant was sold I have allowed capital expenditure figures to fall accordingly. Hence gross investment in any year is simply the increment in capital expenditure.

Not all undertakings drew up their balance sheets at the same time. Companies usually drew them up at the end of December. English local authorities usually drew them up at the end of March, and Scottish local authorities at the end of May. There were a few exceptions to these rules. I have not attempted to correct for this. New plant was usually installed in the summer, and thus I have taken the gross investment of all undertakings and put it in the nearest calendar year. This would cause my capital expenditure series to lead the true series slightly.

Additions to capacity Table 16.

The same procedure was adopted as for capital expenditure except that no allowance was made for years before supply began.

The aggregate estimated capacity in the more uncertain group as a percentage of the total estimated capacity was

<table>
<thead>
<tr>
<th>Year</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1896</td>
<td>7.5</td>
</tr>
<tr>
<td>97</td>
<td>7.9</td>
</tr>
<tr>
<td>98</td>
<td>7.5</td>
</tr>
<tr>
<td>99</td>
<td>6.5</td>
</tr>
<tr>
<td>1900</td>
<td>6.3</td>
</tr>
<tr>
<td>01</td>
<td>6.8</td>
</tr>
<tr>
<td>02</td>
<td>8.7</td>
</tr>
<tr>
<td>03</td>
<td>9.5</td>
</tr>
<tr>
<td>1905</td>
<td>5.8</td>
</tr>
<tr>
<td>06</td>
<td>7.4</td>
</tr>
<tr>
<td>07</td>
<td>7.3</td>
</tr>
<tr>
<td>08</td>
<td>7.3</td>
</tr>
<tr>
<td>09</td>
<td>7.1</td>
</tr>
<tr>
<td>1910</td>
<td>7.1</td>
</tr>
<tr>
<td>11</td>
<td>6.8</td>
</tr>
<tr>
<td>12</td>
<td>6.3</td>
</tr>
</tbody>
</table>
Some check can be made on these figures by data in the 1907 and 1912 Censuses of Production. However the census figures are not unambiguous as tramway power houses belonging to municipalities are grouped together with municipal electricity supply. Also there is reason to suspect that the Lots Road power station of the Underground Electric Railways of London is included among company electricity supply. My estimates of the capacity of British central stations are 960,481 KW in 1907 and 1,403,774 KW in 1912. The Census gives 1,020,312 KW in 1907, but I estimate that 72,848 KW was in municipal tramway power houses and 44,000 KW was at Lots Road. Deducting these two amounts leaves 903,464 KW. My estimate is 106% of this figure. In 1912 the Census gives 1,481,275 KW, I estimate 109,345 KW was in municipal tramway power houses and 44,000 KW was at Lots Road. Deducting this leaves 1,327,930 KW. My estimate is again 106% of this.

---

Estimation of generation and sales of electricity by electricity supply undertakings. Table 22.

I have used figures published in Garke's Manual. These contain data relating to most undertakings, except the power companies. The sales figures (in KW) in Garke's Manual have already been added up. But the method used is unsatisfactory. Firstly the figures are given for the year in which the Manual appeared, although the accounts refer to an earlier year. Secondly some accounts of some companies for some years are missing. These omissions lead to underestimation of totals. Thirdly - a small point, - the Manual covers all companies registered in Britain.
Electricity sold in South America and India appears to be included.

Garke's information on the power companies is very deficient. N.E.S. Co. is excluded after 1905, although it is very important. Other power companies are also excluded. The power companies' figures are not centrally collected. Neither the Electricity Council nor the Central Electricity Generating Board have any knowledge of them. However N.E.S. Co. figures have been obtained from the North Eastern Electricity Board. For other power companies estimates have been made from figures of connections to mains given in the Electrical Trade Directory plus data of KWh sold p.a. per KW connections, derived from N.E.S. Co. data. Also odd figures have been found in the Electrical Trades Directory and in annual reports of the power companies. The figures for the power companies are rather shaky, but checks with the 1907 and 1912 Censuses suggest small margins of error. Estimation was based on individual undertakings and then all figures were added up. Sales were first estimated. Graphical interpolation was generally used to estimate figures for years where they are missing.

One deficiency in the published figures was that sales figures were usually not given for an undertaking in the year in which it began supply. As when most undertakings began, electricity was largely sold for lighting, the bulk of units sold were in the winter. Also when most undertakings began accounting years ended in December (even in the case of local authority supply). Thus it was felt that on the average the sales in the year when supply began would on the whole be half those in the next year. A random sample of 20 undertakings, where sales in the year when supply began are 1. Except for the Derby & Notts Power Co.
available, was taken and the statistic sales in first year of supply/sales in second year was calculated. The average value of this statistic for the sample was 0.504, with a variance of 2.108. Thus missing sales figures for the first year of supply were estimated at half the sales of the second year.

In Column 5 of Table 22 sales figures have been connected to an annual basis. The local authority figures for years ending in March and May both showed strong linear trends.

As the 1907 Census gives figures of generation, but incomplete figures of sales, generation figures were collected, estimated and aggregated. There were many more gaps in generation figures. An attempt was made to estimate missing figures for the whole population by taking random samples at three yearly intervals, and estimating intermediate points graphically. However the variance of this statistic was very high, and thus it would not have been an efficient estimator. It was found that the statistic much more constant for an individual undertaking over a range of six years or so. Thus where it was available for nearly years it was used to calculate units generated from units sold. When the statistic for the individual undertaking was not available the statistic from the random samples was used.

The checks with the Censuses of 1907 and 1912 are difficult because of the peculiarities of the Census data. But for 1907 the adjusted Census generation total is 1165 in KWh. My estimate is 1102m. KWh, the difference being only 6%. For 1912 the adjusted Census figure is 1861m. KWh. My estimate is 2181m. KWh. But the Census of that year was incomplete.

However, the fact that my estimate is 13% greater than the Census may

1. See P493 for reasons for adjustment of census total.
indicate greater inaccuracy in my estimation towards the end of the period because of the greater importance of the power companies.

Estimates of traction sales were done by graphical extrapolation and interpolation. As most figures were already given, and estimates were made easy by the fact that most tramways caused a sudden bulge in electricity sales, one would not expect too many errors. It has been difficult to estimate sales to the Brighton Railway which makes the estimates from 1909 on more shaky.

Estimation of power sales was done either by graphical interpolation of use of the statistic units sold p.a. per customer. This was often available for undertakings in the days when electricity was only used for lighting. The variance of this statistic when calculated for all undertakings using only lighting for several years was found to be intolerably high. But it was fairly constant over a range of years for one undertaking. Sometimes a mixture of graphical interpolation and the latter statistic were used. As the average revenue varied for units sold for different purposes changes in average revenue were helpful. But the whole method was rather impressionistic, especially for the early years of a company's power sales.

Data on power sales often appears from one to three years after such sales begin. Again the power companies were the most troublesome. Considerable trouble was taken over N.E.S. Co. which accounts for a very large share of sales of electricity for power. For the others it was assumed that the Cleveland & Durham, the Clyde Valley, the Lancashire, the South Wales and the Yorkshire power companies sold electricity only for power, while the others sold only to authorised distributors. It is likely that the power sales of the
others will cancel out against the non power sales of the former five.

The methods used for estimating sales for power are crude. Unfortunately estimates are a considerable proportion of total sales for power. In 1907 estimates made up 43% of the total. Yet although crude it is not likely that better results could be achieved, except perhaps with an excessive input of resources.

In the years 1912 - 13 power sales are more difficult to estimate than earlier. My sum of individual estimates for 1913 came out at 911m. KWh. This seems too low and I have rather arbitrarily increased it to 1,000m. KWh.

The only check we can make on the estimates of sales for various uses is with the 1907 Census. This is done below. At first sight the differences seem enormous.

<table>
<thead>
<tr>
<th>My estimate</th>
<th>1907 Census figures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Units generated</td>
<td>1101.9</td>
</tr>
<tr>
<td>Units sold ... total</td>
<td>956.0</td>
</tr>
<tr>
<td>&quot; &quot; lighting</td>
<td>416.0</td>
</tr>
<tr>
<td>&quot; &quot; traction</td>
<td>218.9</td>
</tr>
<tr>
<td>&quot; &quot; power</td>
<td>321.1</td>
</tr>
<tr>
<td>not separately distinguished</td>
<td></td>
</tr>
</tbody>
</table>

The main difference lies in sales for traction. But it is fairly simple to explain. In the census Municipal tramways generating their own current are included in municipal supply, although company tramways generating their own supply are shown as users generating their own current. Although the Census gives no figures of generation in municipal tramway power houses, it is possible to estimate the amount from Carke's Manual. Such trams used 146.7m. KWh in the relevant time period. The Board of Trade Returns relating to tramways shows that municipal tramways used 324.8 m. KWh. If
248.7 was own generated current, purchases from public supply stations was
176.1m. Kwh. Carriage trams purchased 49.0m. Kwh, and the N.E. Railway
purchased 14.8m. Kwh. 1

\[ 176.1 + 49.0 + 14.8 = 234.6 \text{m. Kwh.} \]

This 234.6m. Kwh is 7.5 above my estimate of sales for traction. The
difference is partly due to the impossibility of completely reconciling
Government figures from different sources. For example the Census shows
trams purchased using 107.1m. Kwh and the Board of Trade returns show them
using 107.1m. Kwh. However it is also due to the imperfect methods of
estimation I have used. As pointed out in Table 18.4m. Kwh used for
traction cannot be allocated between own generation and purchases.

Yet there is still a big difference between 442.4m. Kwh minus
147.8m. Kwh = 294.6m. Kwh and the 234.6m. Kwh calculated above. The
difference of 60.0m seems to be accounted for by peculiarities in sales to
railway companies which suggests that the Lots Road power station of the
Underground Electric Railways of London Ltd. was included as a public supply
company although it only sold current to its subsidiary and affiliated
underground railways (District, Baker Street & Waterloo, Piccadilly and
Charing Cross and Euston). In the Census railway companies are entered
as buying 110.9m. Kwh. Only the N.E. Railway (excepting the above tube
lines) bought it for traction. 110.9 - 14.8 = 96.1m. Kwh. This is a
very high figure for station lighting etc. and is also inconsistent with
other figures. The Census gives a figure of 174.4m. Kwh. for generation
by railway companies. It is incomplete and probably ought to be increased
to 176.0m. If we allow 15% losses (the usual figure) and add purchases we
1. N.E. Railway bought 14.8m. altogether - only 9.5 was for traction.
have 260.9 m. KWh for use. The Board of Trade Returns for electric railways
give their use of electricity as 213.7 m. KWh. 260.9 - 213.7 gives only
47.2 m. KWh for station lighting railway workshops etc.

There are no figures available of generation at Lots Road or
purchases from it by the tubes. But if we take the electricity used by
electric railways and deduct the amount used by the N.E. Railway plus
estimates of the amount used by the Lancashire & Yorkshire Railway the
Mersey Railway and the Liverpool Overhead we get approximately 175 m. KWh.
The rest was used by the London Underground Railways. Those of them
buying current from Lots Road carried 43½% of the total passengers. If they
used 43½% of the total current used they used 84 m. KWh. Lots Road had a
capacity of 44,000 KV. If the maximum demand was 35,000 KV at the load factor
was 30% generation would be 92 m. KWh. Thus purchases of 84 m. are reasonable.

This suggests that of the 110.9 m. KWh sold to railways 84 m. + 14.8 m.
was for electric traction and 12.1 m for non electric railways for station lighting,
railway workshops etc. Also it suggests that 47.2 - 12.1 = 35.1 m. KWh
was generated by steam railways for station lighting and railway workshops.

This is finally confirmed by the fact that the Census states that
railway companies used 194.7 m. KWh for traction. The N.E. Railway,
the only one buying electricity for traction from public supply station,
used only 9.5 m. KWh. Thus railway companies must have generated (194.7 - 9.5)
= 185.2 m. KWh (after losses) for traction themselves. Thus some these units
must be entered in the Census as purchases from outside. These can only have
come from the Lots Road power station.

This more than accounts for the lost 44.7 m. KWh. But the census
breakdown of sales was incomplete.

The best check on those figures seems to be correct figure of generation in the Census by deducting generation in municipal tramway power houses, and at Lots Road and to compare the result with my figures of generation, which come from the same source as my figures of sales. Thus from 1432.1 deduct $\frac{4\times0.7}{0.05}$ (to allow for usual losses) and 92. There is no easily recognisable result. It is consistent with my figure of 1102m. KWh.

Once the traction difference is explained it is clear that the census figures for power and lighting may simply be less than my figures because they are incomplete. Thus they tend to support, but do not check my estimates. One more figure is available. Mining and manufacturing bought 283.5m. KWh in 1907. Railway companies also bought at least 12.1 + 5.3 (N.R. Railway) in KWh = 17.4m. KWh for traction purposes. Some of this 300.7m. or more units was for lighting but most was for power. Also in so far as they bought electricity from local authorities the figure is not comparable with power sales by utilities, as the local authority year ended on 31 March 1907.

Lighting sales are a total sales less sales for power and traction.

The use of electricity in 1907 and 1912 - Table 25.

Because much electricity was generated by the mining and manufacturing sector, the amount of electricity used can only be estimated for 1907 and 1912. Unfortunately the Census figures are incomplete. Nevertheless rough estimates of the quantity of electricity used are possible.
In 1907 returns were made of electricity generated by mining and manufacturing companies. But they relate to generation by only 68% of the capacity of dynamos used. I have assumed that the dynamos for which returns were not made generated as much electricity per KW capacity as those for which returns were made. Several objections could be made against this correction, but no basis is available for a better method, and it seems better than simply ignoring 32% of the dynamo capacity in existence.

On this basis industry generated 1035m. KWh. Assuming losses of 6% (central stations themselves used about 6% of the electricity they generated; isolated installations would use a smaller proportion, but there would be some distribution losses). 973m. KWh. were used. Most of this was for power.

In 1912 no figures of generation are available. In the absence of information for a more sophisticated calculation I have multiplied 973m. KWh by dynamos installed in 1912/dynamos installed in 1907

\[ \frac{973 \times 1142}{591} = 1880. \]

In 1907 non electric railway companies seem to have used 35m. KWh for station lighting, railway workshops etc. which they generated themselves. In 1912 no data is given on this. Let us simply double the 1907 figure and assume they used 70m. KWh which they generated themselves.

The traction figures come from Table 52. Public supply figures from Table 24.

These figures relate to the calendar year in the case of all companies, and to the nearest financial year in the case of local authorities.
Gross Investment on Electric Tramways - Table 35.

Figures of capital expenditure on tramways are given annually in the Board of Trade returns relating to tramways. As depreciation provision was normally in the form of sinking funds, increments of capital expenditure are very good estimates of gross investment. Unfortunately many new electric tramways obtained their powers under the Light Railways Act and not the Tramway Act. The undertakings operating under the former Act were not included in the Tramway Returns until 1903.

Thus capital expenditure before the end of 1903 was estimated on the basis of the miles of electric tramway open. This is given for most but unfortunately not all years in the Electrical Trades Directory. There are no figures for 1896, 1898, 1901 and 1902. Before 1893 the figures are generally poor. Between the end of 1897 and the end of 1903, 1874 miles of electric tramway were built while capital expenditure rose by £31 - 32 million. Thus each route mile cost approximately £23,000. This is consistent with a cost of £28,437 per route mile for track built between 1903 and 1909. From the £23,000 per mile and the mileage the following gross investment series emerges.

<table>
<thead>
<tr>
<th>Year</th>
<th>£m</th>
<th>Year</th>
<th>£m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to end of 1893</td>
<td>.53</td>
<td>1898 &amp; 9</td>
<td>4.23</td>
</tr>
<tr>
<td>1894</td>
<td>.11</td>
<td>1900</td>
<td>7.0</td>
</tr>
<tr>
<td>1895</td>
<td>.40</td>
<td>1901, 02, 03</td>
<td>20.35</td>
</tr>
<tr>
<td>1896 &amp; 7</td>
<td>.98</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Up to 1900 the gross investment of each calendar year was then allocated by graphical interpolation of the missing capital expenditure figures. For 1901, 02 & 03 each year has been allocated one third of the capital expenditure in the three year period. There is no information which one
would use to improve this.

After 1903 the figures come straight from the figures of capital expenditure. For the municipalities the accounts run generally from March to March, for the companies from December to December. No allowance has been made for this. Local authority investment has been put in the nearest calendar year.

The use of electricity for traction - Table 52.

1. Electric Tramways.

The total amount of electricity used by tramways is given by the Board of Trade Returns relating to Tramways and Light Railways. The amount purchased from public supply station was taken from my estimates. The amount generated in tramway power houses was taken to be the remainder. A check made in 1907 shows that this cannot be quite correct; for an independent estimate (made from figures in Garke's Manual, and the 1907 Census of Production) of the electricity used which was generated by the tramways themselves, when added to my estimate of the amount bought from public supply stations leaves 18.4m. KWh unaccounted for.

2. Electric Railways.

The Board of Trade Returns relating to Electric Railways gives the amount of electricity they used from 1905 onwards. Only two electric railways bought electricity from public supply stations, the N.E. Railway and the London, Brighton & South Coast Railway. Sales to the N.E.R. are given in the N.E.S. Co. historical statistics. Sales to the L.B. & S.C.R. have been estimated graphically from the data relating to the London Electric

Not all the electricity used by tramways and electric railways was for traction, but most of it was. In 1907 electric railways used 213.7m. KWh (Board of Trade Returns), and 194.7 (91% of this) (Census of Production) was used for traction. I have included under traction all electricity used by electric tramways and electric railways.

London Transport passengers - Table 51.

Buses.

Statistics are only available for the two principal companies, the London General Omnibus Co. and the London Road Car Co. The first Report of the London Traffic Branch of the Board of Trade (H.P.R., 1908 Vol. 93) thought that bus passengers in 1907 totalled about 500 million, as against 364 million by the two major companies.

Other local railways.


Suburban traffic on main line railways.

In October 1907 a census was taken of passengers booking tickets to London at all stations within a 30 miles radius of Charing Cross. I have multiplied this figure by 24 to get an estimate of suburban journeys to and from the centre of London. In October 1911 a similar census was taken, and the same procedure used to get a 1911 estimate of suburban journeys. For 1903 an estimate was made as follows: Five companies, the Great Eastern,
the Great Northern, the London & S. Western, the S.E. & Chatham and the
London, Brighton & S. Coast, lost 34 million passengers p.a. between 1903
and 1907, a fall of 9.7%. As receipts fell by only 1.7%, the reduction was
in suburban passengers. Long distance traffic was said to have risen
slightly. All the fall of 34 million was assumed to be a fall in suburban
passengers and a similar fall was assumed in the suburban traffic of the
Great Western, the Great Central and the Midland - i.e. 2 millions. 1903
suburban traffic was then simply estimated at 144 + 36 = 180 millions.

All these figures exclude season ticket holders. For 1907 only,
figures are available for journeys to London which include them. If I had
included them the estimate of suburban passengers for that year would have
been 171 millions - 19% more than 144 millions.

A check in the estimates of suburban passengers from information
collected by the Royal Commission on London Transport. They tabulate the
hours of arrival and departure of passengers at main line station on an
average weekday in 1903 (B.P.P. 1906 Vol. 66 PP 658 - 9) If we assume
long distance traffic follows a regular curve and that all midday traffic
is long distance, we can calculate the traffic in the morning and evening
peaks. This should provide a minimum estimate of suburban passengers.
The resulting figure is 150 million p.a.

A check on the number of season ticket holders is provided by
the Royal Commission's table (B.P.P. 1905 Vol. 30 PP 603 ff) showing
arriving at and leaving main line stations in 1903. 206 million were on
ordinary tickets, 104 million on season tickets. Comparing this result
with 1907 a big fall off in season ticket holders is shown, indicating that
it was particularly the commuters who switched to the trams. Thus the fall in suburban traffic between 1903 and 1907 may have been considerably more than 36 millions.

**Motor power in mining and manufacturing - Table 54**

What is required is the proportion of power applied to tools etc. by electric motors. There is a considerable amount of data relating to power in the 1907, 1912 and 1924 Censuses of Production. Unfortunately they give different types of information. The 1907 Census gives incomplete information of the amount of electricity used; the incomplete 1912 census (it only collected data from establishments employing more than 5 persons) gives information about the horse power of electric motors. Both give the total amount of factory power used, and the total power of dynamos in factories.

First a ratio was derived of dynamos: motors driven by electricity generated on the premises. In 1912 and also for 1924 data is available to calculate this. But electricity was also used for lighting and the proportion used for lighting was certainly higher in 1907 than 1912. Electricity was also used for electrolysis and thus the non-ferrous metals group was eliminated. For all other groups the ratio was 1.225 in 1912 and 0.884 in 1924. This is consistent with a smaller proportion of electricity generated being used for lighting. A ratio for 1907 was found by taking the p.a. difference between the ratio in 1907 and 1912 and extrapolating it backwards (giving a result of 1.367). This was used to estimate the motors on own generated electricity in 1907 (565,000 h.p.) The Electrical Trades
Directory gave an estimate of motor power (excluding traction connected to public supply mains for 1907 and 1912. That for 1912 is 99.4% of the Census total. But the 1912 Census was incomplete. Thus the motor connections figure for 1907 was taken as a good estimate, as it was hoped that gaps in the E.T.D. figures would be compensated for by making no deduction for non-ferrous metal.

For 1912 and 1924 the Census figures giving the h.p. of motors on own generated and purchased electricity were used. Total electric power was taken to the sum of these two figures.

Estimates of mechanical power are crude. From the total, that used to drive dynamos (assuming 90% dynamo efficiency, as do the compilers of the census) was deducted. It was assumed that mechanical transmission losses equalled diversity, (because tools etc. were not used all the time the engine power required could be less than the aggregate power of all tools).

The method is inevitably crude. One check is provided by the 1935 Census which gives figures of the power equipment of industry in 1924. For motor power in mining and manufacturing excluding non-ferrous metals they are

<table>
<thead>
<tr>
<th>Power applied electrically</th>
<th>% of total</th>
<th>Power applied mechanically</th>
<th>Total power</th>
</tr>
</thead>
<tbody>
<tr>
<td>6110</td>
<td>49.5</td>
<td>6216</td>
<td>12327</td>
</tr>
</tbody>
</table>

% of my estimate for 1924 85 87.5 86.3

Thus the figures in Table 54 may be generally overestimated, but the percentage of electrification figure differs by a negligible amount.
I have used the figures given in the 1924 Census throughout. The 1907 Census gives slightly different figures for 1907. For individual census groups (given in Table 93) the difficulties of manipulating the 1907 Census figures is greater, as the ratio of dynamos: motors run from own generated electricity varies from group to group, and we do not know how the motor connections given in the E.T.D. should be allocated among groups.

The figure for motors run from own generated electricity was obtained for each group by extrapolating backwards the p.a. difference between the 1912 and 1924 ratios of dynamos: motors run from own generated electricity.

The figure for motors run on electricity purchased from outside was derived by taking the statistic kWh p.a. purchased/Total power of motors driven by purchased electricity. This was then multiplied by an index number of statistic kWh p.a. generated/power of motors driven by own generated electricity for each group. (The average kWh p.a. generated/power motors driven by own generated electricity = 100.) The amount of electricity purchased by each industrial group was then divided by the appropriate resultant figure. This is not a very good method, but perhaps suffices.

Gross output of electrical machinery, — Table 72

An attempt has been made to prepare a time series of the gross output of electrical machinery. Electrical machinery is here defined as generators, motors, connectors, transformers, switchgear, and arc lamps.

1. Arc lamps are included for convenience. They were nearly all bought by municipalities operating central stations and factories using electric power.
<table>
<thead>
<tr>
<th>Industrial Group</th>
<th>1907 Electric motors in 000 h.p.</th>
<th>% of total power</th>
<th>1911 Electric motors in 000 h.p.</th>
<th>% of total power</th>
<th>1924 Electric motors in 000 h.p.</th>
<th>% of total power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mines and Quarries</td>
<td>1.127</td>
<td>5</td>
<td>2.290</td>
<td>2,417</td>
<td>1.614</td>
<td>41</td>
</tr>
<tr>
<td>Tin and Steel</td>
<td>80</td>
<td>4</td>
<td>1,873</td>
<td>1,953</td>
<td>1,027</td>
<td>90</td>
</tr>
<tr>
<td>Iron and Steel</td>
<td>195</td>
<td>12</td>
<td>1,414</td>
<td>1,609</td>
<td>1,320</td>
<td>46</td>
</tr>
<tr>
<td>General and Electrical Engineering</td>
<td>199</td>
<td>51</td>
<td>192</td>
<td>391</td>
<td>1,027</td>
<td>90</td>
</tr>
<tr>
<td>Mines, Motors &amp; Railway Engineering Waggons</td>
<td>21</td>
<td>38</td>
<td>33</td>
<td>56</td>
<td>24.9</td>
<td>92</td>
</tr>
<tr>
<td>Mine Engineering &amp; Shipbuilding</td>
<td>83</td>
<td>55</td>
<td>68</td>
<td>151</td>
<td>362</td>
<td>95</td>
</tr>
<tr>
<td>Met.</td>
<td>23</td>
<td>15</td>
<td>136</td>
<td>159</td>
<td>14.9</td>
<td>53</td>
</tr>
<tr>
<td>Al, Drink and Tobacco</td>
<td>54</td>
<td>14</td>
<td>326</td>
<td>380</td>
<td>40.3</td>
<td>61</td>
</tr>
<tr>
<td>Printing</td>
<td>36</td>
<td>34</td>
<td>70</td>
<td>106</td>
<td>103</td>
<td>59</td>
</tr>
<tr>
<td>Medical and Allied</td>
<td>46</td>
<td>18</td>
<td>215</td>
<td>261</td>
<td>103</td>
<td>72</td>
</tr>
<tr>
<td>Paper, printing and Allied</td>
<td>58</td>
<td>23</td>
<td>193</td>
<td>251</td>
<td>344</td>
<td>66</td>
</tr>
<tr>
<td>Other, Canvas and India Rubber</td>
<td>9</td>
<td>17</td>
<td>46</td>
<td>56</td>
<td>153</td>
<td>77</td>
</tr>
</tbody>
</table>

Table 93: Motor power in mining and manufacturing by industries.
Much electrical machinery was sold to electrical utilities (central stations, electric trains, electric railways.) Although for most of these utilities fairly good gross investment figures can be obtained, there is much less information about the amount spent on various pieces of equipment. Nevertheless for the three major groups of utilities (electricity supply, electric tramways and the London underground railways) this was done.

Central stations often gave figures of capital expenditure on various items. Random samples were taken for each year. The percentage in the various categories is remarkably constant over the period 1896 - 1913. Most electrical machinery comes under the heading "plant & machinery", but would comprise only part of this category.

The Board of Trade Returns relating to Tramways & light railways give from 1903 onwards expenditure on the electrical equipment of the line and on tramcars. Tenders for tramcars show that 42% of the cost of a tramcar was its motor equipment. The percentage of capital expenditure on electrical equipment varies in the years 1903 - 1914, but shows a declining trend. This trend was crudely extrapolated backwards into the 1890s. Much of the expenditure on electrical equipment was on cable and overhead wires. It was assumed that one third of the expenditure on electrical equipment was on electrical machinery. This is a crude assumption.

For the London underground the situation is worse. Only for the Waterloo & City Line are there published figures of the purchase of electrical

1. Land and Buildings, Plant and Machinery, Instruments, Mains, meters, miscellaneous, including legal charges.

2. See Table 27.
equipment. This was 11% of total capital expenditure by the time the line was opened. It was assumed that this percentage applied to other lines. A much smaller proportion of expenditure on electrical equipment was in cables compared with the trams. It was crudely assumed that 3/4 of expenditure on electrical equipment was on machinery.

The three sets of figures thus obtained were summed and an allowance of an extra 20% made for purchases by utilities out of revenue. The only major utility not included was main line railways. However they only became important purchasers of electrical machinery just before 1914. It is unlikely that the N.E.R. and the L. & Y. Railway spent more than £0.25m each on electrical machinery for their 1903-4 electrification schemes.

The series was compared with the gross output figure for electrical machinery plus arc lamps in the 1907 Census of Production after the export balance (exports minus imports) had been deducted. The remainder, which was rather surprisingly high was largely sales to factories for factory electrification, both motors for factories buying electricity from public supply stations and dynamos and motors for factories generating their own electric power. 1907 seems to have been a rather isolated year of high investment in factory electrification. This is shown in the Electrician's series of connections to electricity supply mains, and in my figures of the increments of sales of electricity for power from public supply stations.

This figure of sales to non-utility home buyers for 1907 was used together with an index for the use of electricity for power, and a price index, to derive figures of sales of plant to non utilities for other years.

The use of electricity for power index was simply the increments in the sales of electricity for power by public supply stations. (See this appendix P 492). The price index used was calculated from figures of the cost of KW of new central stations. (See Table 23, appendix to Chapter 3.) As the percentages of capital expenditure for various parts of the supply system did not change over the period it was assumed that it could be used for electrical machinery.

The whole series of sales of electrical machinery at home is very crude. However it does show long run trends reasonably. It does not seem to be very good in the years 1910 - 1914. The Parsons Committee gave a figure for the gross output of all the electrical trades just before 1914. This was double the 1907 figure. However we know that there was a great increase in the volume of output from 1911 - 1914. My figures exclude main line railway electrification, which was important in those years. My estimates of the sale of electricity for power are probably deficient after 1911. My price index probably overestimates the fall in prices after 1909 - 10 as central station costs fell then partly because of economies of scale, which did not exist in factory electrification plant. But before 1910 the series does not seem too bad.

Shares of the Central Station Market. - Table 80.

The Electrical Trades Directory gave details of the generating plant of most central stations. By comparing details of adjacent years it is usually possible to see who the makers of new dynamos installed were.

1. Report on the Electrical Trades after the War, Cd. 9072.
As figures of capacity were given and capacity of machines bought from individual manufacturers were usually given all measurements are in kW. Usually the size and maker of new generators is easy to determine. Sometimes however several new generators were installed and only the aggregate capacity can be calculated. When the number of machines supplied to each maker is available the aggregate added capacity has been allocated to each maker proportionately to the number of machines he provided. Sometimes it is impossible to know the maker of new plant. There are also some internal inconsistencies in the figures, owing largely it seems to different measures of capacity of the same machines.

Generators which cannot be allocated to individual makers as a percentage of all generators added.

<table>
<thead>
<tr>
<th></th>
<th>Up to end of 1892</th>
<th>Up to end of 1904</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>52</td>
<td>0</td>
</tr>
<tr>
<td>93</td>
<td>15</td>
<td>0</td>
</tr>
<tr>
<td>94</td>
<td>31</td>
<td>5</td>
</tr>
<tr>
<td>95</td>
<td>8</td>
<td>25</td>
</tr>
<tr>
<td>96</td>
<td>29</td>
<td>0</td>
</tr>
<tr>
<td>97</td>
<td>26</td>
<td>5</td>
</tr>
<tr>
<td>98</td>
<td>27</td>
<td>5</td>
</tr>
<tr>
<td>99</td>
<td>26</td>
<td>6</td>
</tr>
<tr>
<td>1900</td>
<td>21</td>
<td>11</td>
</tr>
<tr>
<td>61</td>
<td>37</td>
<td>12</td>
</tr>
<tr>
<td>62</td>
<td>0</td>
<td>13</td>
</tr>
</tbody>
</table>

Table 80 is thus liable to considerable errors. But having gone through the changes in plant from year to year for each central station, one is left with the strong impression that in fact the errors are quite small if we take several years together. We cannot place very much reliance on the figures of market shares for any given year. However one would not want to do this even if there were no errors in the data.
Some plant was scrapped. No perfect allowance can be made for this, although the errors introduced by imperfections here must be very small.

Total capacity added by all new generators derived in this way is given below, it can be checked with my estimates (Table 16) of capacity added - which come from a different source. Although the correspondence between the two is not very good from year to year over a few years the two give similar results.

<table>
<thead>
<tr>
<th>Year</th>
<th>KW</th>
<th>Year</th>
<th>KW</th>
</tr>
</thead>
<tbody>
<tr>
<td>1893</td>
<td>9,492</td>
<td>1904</td>
<td>118,031</td>
</tr>
<tr>
<td>94</td>
<td>15,342</td>
<td>95</td>
<td>57,706</td>
</tr>
<tr>
<td>95</td>
<td>12,473</td>
<td>96</td>
<td>76,237</td>
</tr>
<tr>
<td>96</td>
<td>22,635</td>
<td>97</td>
<td>71,265</td>
</tr>
<tr>
<td>97</td>
<td>12,972</td>
<td>98</td>
<td>76,680</td>
</tr>
<tr>
<td>98</td>
<td>32,410</td>
<td>99</td>
<td>60,401</td>
</tr>
<tr>
<td>99</td>
<td>59,104</td>
<td>1910</td>
<td>61,571</td>
</tr>
<tr>
<td>1900</td>
<td>88,505</td>
<td></td>
<td></td>
</tr>
<tr>
<td>01</td>
<td>128,022</td>
<td>12</td>
<td>95,929</td>
</tr>
<tr>
<td>02</td>
<td>77,753</td>
<td>13</td>
<td>139,008</td>
</tr>
<tr>
<td>03</td>
<td>109,583</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Gross Investment in Fixed Capital in the Electrical Industry.**

- Table 91. Column 3.

According to the Census of Production of that year factories had 609,654 KW of dynamos installed. This has been multiplied by the sales of electricity for power from public utilities (in index form 1907 = 100) to give some idea of capacity in other years. The increment in capacity has been found and multiplied by the cost per KW of power stations (Table 26 x 0.546 - the average proportion of capital expenditure spent on the power station.) It is thus assumed that the smaller amount
of constructional work involved in the generating plant in a factory is
offset by the higher cost per KW of the smaller plant installed in factories.
The resultant series is very crude.

Average Size of Generators, Table 21.

As for Table 80 except that only figures where the size
of the generator is precisely known are included.
1. Generation of electricity.

A dynamo produces electrical energy by passing a conductor through a magnetic field. As the conductor passes through the field a voltage is induced in it which rises to a peak and falls away again. Below is shown an alternating current dynamo (known as an alternator).

As the conductor rotates in the magnetic field alternately positive and negative voltages are produced. The voltage is collected from the rotating conductor by slip rings. The voltage fluctuates in a wave like way (a sine curve). This is shown in the next diagram.

The useful voltage developed by an alternator is the root mean square of the instantaneous voltage over a complete cycle. The frequency of a.c. is measured in complete cycles per second (written as $\omega$).

A d.c. generator consists of a whole series of conductors. Together they are known as the armature. Each conductor (armature coil) is connected to two segments of a commutator. The commutator consists of wedge shaped copper bars, insulated from each other, set longitudinally along a drum. Against opposite sides of the commutator are two brushes which collect successive waves of voltage from each coil as it passes through the magnetic field. These waves of voltage approximate to a constant positive flow, as is shown in the following diagram.

Because the brushes are constantly making and breaking contact with the bars of the commutator, a certain amount of sparking will occur. This sparking makes the generation of high voltage difficult. D.c. generators provide current for their own (electro) magnetic fields (self excitation). Alternators, however, cannot do this, and an exciter (a d.c. generator) is needed to generate current for the field coils.

1. ibid. PP 109 - 10.

2. at least - an even number is necessary.

3. J.A. Fleming, op.cit. P 121 - 6, the theory of alternators.
Arc lighting dynamos were designed to produce a constant current (measured in amps). Other dynamos were designed to produce a constant pressure (measured in volts).

The first alternators were single phase. A polyphase alternator produces two or more currents which reach peaks at different times (i.e. are out of phase). A two phase alternator is wound with two sets of coils, the second set usually being 90° behind the first. Thus two sine waves of voltage are produced, one lagging slightly behind the other.

A three phase alternator has three sets of armature coils set at 120° difference from each other. This produces three sine waves of voltage.

1. Power, i.e. rate of doing work, conventionally measured in K.W. = Volts x amps.

2. This is not strictly true. Gramme made some polyphase alternators in the very early days. (P.S.) But they were used as single phase machines.
2. **Transmission and Distribution.**

A given power (K.W.) can be transmitted either at a high voltage and small current or at a low voltage and high current. Conductors were usually copper (aluminium was used at the end of the period for some purposes), and the cross sectioned area of copper required to convey a given power is inversely proportionate to the square of the voltage. High voltage mains are more expensive to insulate, but it is clear that there are great potential economies in transmitting at high voltages.

Electrical appliances may be connected up to distribution mains either in series or parallel. Arc lamps worked better when connected in series. The matter is best illustrated in the following diagram.

![Diagram](image)

1. This and the next diagram come from H.C. Passer. *op.cit.* P 81.
The voltage on such a circuit is additive. If each lamp takes 45 v. and there are 9 lamps the generator must provide a voltage of $9 \times 45 = 405$ v. Each extra lamp raises the voltage required. All lamps are switched on and off together.

A parallel circuit is illustrated below.

![Diagram of parallel circuit](image)

The voltage is constant throughout. Each appliance is separately controlled. The current the generator must provide depends on the total resistance (power of appliances) in the circuit.

These circuits apply both to d.c. and single phase a.c. 2 phase a.c. required 4 wires, two for each phase. 3 phase a.c. required three wires, one for each phase. No return wire is required as positive and negative electro motive forces cancel out when all phases are taken together.

3. The use of electricity.

Most electrical devices work at a constant voltage. Arc lamps however require a constant current. The resistance presented by an arc lamp to an electrical current is inversely proportionate to the current. This can lead to unstable operation. If for example, the arc light

1. Ohm's Law.
resistance should happen to decrease slightly (because an imperfect carbon feed mechanism reduced the length of the arc), the current would increase, the resistance would decrease, and so forth. Hence the need for a special dynamo which kept the current steady. Incandescent lamps on the other hand required a carefully regulated voltage. Small fluctuations, i.e., more than about $4\%$—could cause the filament to break or only glow red.

Motors are the inverse of generators, converting electrical into mechanical energy. A d.c. motor receives a steady flow of current which gives it a high torque (twisting movement). The weak point is the commutator. Sparking can occur which makes high voltage operation very difficult. There are three types of a.c. motor, the commutator type, the synchronous type and the induction type. The commutator type is a modified d.c. motor, but has poorer torque, and lower horse power for a given weight than a d.c. motor. Both the field coils and the armature of synchronous motors require current, and thus they need slip rings. Although they thus avoid a commutator the synchronous motor (when used on a single phase circuit) had poor torque. They were not easy to start and if they got out of phase with the generator they stopped. Polyphase current produces two or three magnetic fields rapidly following each other. This provides steadier power. In the induction motor the armature is simply wound with coils but no current is fed to them. Induction motors were particularly suitable for polyphase power. The conjoint effect of the successive magnetic fields produced a rotating magnetic field, which acted on the rotor (the armature) to produce a turning motion.

Although single phase induction motors are now made, before 1914 induction motors were nearly always polyphase. For single phase circuits synchronous or commutator type motors were used.
The evidence for this thesis has come very largely from writings which were primarily concerned with general matters of engineering. To a considerable extent evidence about the economics of the industry has to be collected from odd comments.

The principal contemporary source is periodicals. There were a large number of technical journals which concerned themselves with electrical engineering. After looking at them I came to the conclusion that the best sources were the Electrical Review and the Electrician. Although their primary interest was applied electrical science, they also took an interest in commercial matters. Their comments are usually both fair and shrewd. This contrasts with some other journals.

The Electrical Review and the Electrician have been particularly useful because they contain the papers on matters connected with electricity given to all the principal engineering societies and the discussions on these papers. Hence reference to these papers are to the Electrical Review and the Electrician rather than to the Proceedings of the relevant societies.

Because relevant material is difficult to find I have read every issue of the Electrical Review from 1877 (when it was the Telegraphic Journal) to 1914. I have also extensively used the Electrician, especially for company reports and reports of company meetings. Important evidence has come from records or companies, and the published and unpublished works listed below. However, one of the most useful sources, the general run of comments in the technical press cannot be conveniently listed.

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