# 1. ELECTRIFICATION: AN HISTORICAL PROCESS

Electricity is one of the most pervasive technological forces in developed societies. It is the one universal energy medium. Electro-technology can transmit energy from virtually any primary resource in any location and apply it to any function at any point of use. While energy forms such as coal, petroleum and even animal labour may substitute for electricity in supplying services such as heat and transportation, there is clearly no substitute in power, communications and information technology. In that respect electricity seems to underlie modernity. [1]

The phenomenal growth of electricity supply has left its mark on all modern cities, and Sydney is no exception. Overhead wires, transformers and substations are almost universal features of the urban landscape. So are large tracts of often derelict land once occupied by city power stations. Their obsolescence did not signify the decline of electro-technology, but rather marked the transition to its greatest growth phase. The demand for electricity increased so much that the necessary power stations could no longer be accommodated within the cities they served, and improvements in long distance transmission meant they no longer had to be. Freed of the constraints of the city, electric power generation became perhaps the largest scale of all modern technologies. Power stations and their attendant coal mines or water catchments are the biggest, most resource-intensive machines of the age.

Yet electro-technology began to develop its present forms barely a century ago. Its initial scope was limited, both geographically and functionally, to the lighting of city buildings and streets. There were several reasons why electricity started as a primarily urban phenomenon, and remained so for the next half century. In the first place, the European and North American cities in which the first large scale commercial applications of electric lighting appeared in the late 1870s were already technologically and financially advanced. Their energy markets were dynamic, competitve and receptive to innovation. Their financial and legislative structures allowed the raising of capital and the use of land for urban infrastructure, whether by public bodies or by private entrepreneurs.

The urban lighting market, into which "the electric light" was launched by its inventors and promoters, had already undergone a revolution some fifty years previously with the introduction of coal gas reticulation. Gas had certainly improved the quality of urban lighting compared with the oil lamps and tallow candles it gradually replaced, but its most revolutionary impact lay in separating, for the first time, the site of primary fuel combustion and final energy use. The gas pipes reticulated coal energy throughout the city, and formed a grid capable of supplying energy for lighting and heating at any point. The gas companies were the first modern energy utilities. They developed organisational structures which embraced a range of functions from gas production to customer service, revenue collection, and marketing. Their managers and shareholders rapidly grasped the spatial economics of energy reticulation and ways to exploit their position in the urban energy market.

The urban electricity systems developed along the lines laid down by gas - sometimes literally. Electricity first penetrated the lighting markets in the commercial centres of cities, as gas had done, and then followed the gas pipes to the more prosperous suburbs. At first electro-technology competed only in the high quality commercial and street lighting markets, and left the dispersed residential energy market to gas, wood and other fuels. With the perfection of the electric motor, electricity competed with steam for the supply of street traction and industrial power. Finally, in the last half-century, the electricity system extended into the household and beyond the city.

As electricity penetrated one energy market after another, it integrated the urban and the state energy systems in an unprecedented way. The electricity supply system unified energy consumers temporally, functionally and spatially. Office workers returning home on a cold night in Sydney will cause the rapid release of thousands of tons of water from the hydroelectric storage ponds of the Snowy Mountains. The mains connection of a homestead in the remote west of NSW will affect the price paid for electricity by a shopkeeper in Newcastle.

Electro-technology is now so universal, and the process of electrification so near complete, as to obscure the full historical dimensions of its transformation of the energy system. Accounts abound of key developments in the technology of the electric light, the power station, the electric motor, and even electricity utilities. The only major study in English of the historical process, however, is T.P.Hughes' *Networks of Power: the Electrification of Western Society* (1983). Even so, while Hughes documents and contrasts the technological and political direction which electricity supply took in North America, Britain and Germany in its first half century of growth, he says little on the impact of the new technology on the pre-existing energy systems, structures or indeed societes of the cities he uses as example. These impacts can best be illustrated by defining and synthesising all the major elements of the urban energy system, from supply to use, within a single city.

A vital omission from histories of electricity, even one as comprehensive as Hughes', is the context of energy demand: the ultimate purpose for which the vast apparatus of electricity supply was constructed. Most accounts imply that the growth of supply itself stimulated demand, or that completely new applications of electricity were invented and marketed to take advantage of its unique technological potential. Both are partly true. The postwar boom in home appliance ownership was certainly associated with universal availability of a cheap and reliable electricity supply; aluminium smelting, one of the largest consumers of electricity in NSW, is based on a technology which relies entirely on electricity. Nevertheless much of the electricity used in NSW is still consumed for traditional purposes such as cooking and space heating, and even applications now highly electrified, such as refrigeration, have pre-electric origins. There are underlying trends in energy demand which interact with supply technologies to produce the form of an energy system. These relationships have received very little analysis in the literature of electrification. Energy supply has usually been treated as an isolated physical or engineering phenomenon rather than as part of broader social processes.

How does this interaction take place? What constitutes an urban energy system and what accounts for its degree of electrification? How is the system organised technologically, institutionaly and politically? Is there any limit to its demand for electricity or indeed any other form of energy? A detailed analysis of the electrification process forms an ideal framework for the wider study of the urban energy system.

## 1.1 ELECTRICITY AND THE SYDNEY ENERGY SYSTEM IN 1986

The urban energy system is the entire complex of technological and institutional arrangements which supplies energy to and distributes it within the city. Human settlement at the density of the modern city is made possible by the system's ability to concentrate energy in the forms necessary to sustain the metabolism of the city's inhabitants, and to power the machines on which they have come to rely.[2] Each urban energy system is unique. The balance of energy sources, transportation and non-transportation energy uses varies from city to city, and in any particular city over time. Some of these variations can be accounted for by the physical location of resources and the topography of the city. Others have evolved from peculiarities of ownership, local policy and institutional history..

### Energy Flows Across the Urban Boundary

To define the Sydney energy system it is first necessary to define Sydney. The Australian Bureau of Statistics (ABS) defines a Sydney Statistical Division (SSD) made up of 43 local government areas (LGAs). The total area is 12,407 square kilometres, or 1.5% of the state of NSW, and the estimated resident population in mid 1986 was 3,430,550 or 61.9% of the state total (ABS 1987c).[3]

Sydney has a third dimension as well, of course. The lower bound may be set at 1 km below mean sea level. This is a little below the depth of the Balmain colliery, which operated between 1897 and 1931 (Reynolds & Irving 1971,36), and so represents the deepest level from which energy resources have been extracted within the boundaries of Sydney itself. The upper bound may be set, rather arbitrarily, at 1 km above sea level, to comfortably clear the tallest structure.

There are three separate systems of energy flows across the Sydney boundary. The general climatic system, characterised by heat flows at the land surface and through the atmosphere, is the largest. The second is the biological energy system common to all life forms, characterised by organic chemical energy transformations. The third is the energy system created by human technology to serve the economic needs of human society. The three systems may be termed, respectively, the geo-, bio- and techno-energy systems. The last clearly depends on the first two. Ultimately all draw their energy from astronomical phenomena, in particular the thermonuclear processes of the sun.[4]

The vast majority of the energy crossing the Sydney boundary is in the form of direct solar radiation, heated air and wind. Most of it flows out again almost immediately, or in diurnal and seasonal geo-energy cycles. A small part is captured for the local bio-energy system by plants. The local techno-energy system captures a still smaller fraction by means of solar collectors, heat pumps and windmills. Most of the metabolic energy required by Sydney's human and animal population originates in the bio-energy system outside the SSD. Not enough food is produced within the SSD to satisfy metropolitan demand, and so it must be brought from other parts of NSW, Australia and the rest of the world. The human part of the bio-energy system is heavily dependent on the techno-energy system for food preservation, transportation, processing, refrigeration, preparation and cooking.

The continued functioning of Sydney and other modern cities thus depends on the techno-energy system. Most of the 'primary' energy utilised by the Sydney techno-energy system is collected from the geo- and bio- systems at considerable distance from the city itself. It may be transported to points of use in the city in original form (eg timber) or converted into 'secondary' or 'derived' forms more convenient for transportation and use in the dense urban area (eg electricity). The extent of the primary energy catchment area for the Sydney techno-energy system is illustrated in Figure 1.1.

In 1986, most of the techno-energy flows converging on Sydney were derived from the fossil fuels petroleum, coal and natural gas: bio-energy transformed over time by geo-energy. Coal is formed from the decomposition, compression and heating of plant materials which grew, in the case of NSW bituminous coal, some 220 million years ago (Corbett 1976,52). It is evident that without some cataclysmic change in the earth's geological and climatic conditions, the events which led to the formation of coal and the other fossil fuels will not be repeated. They are essentially 'non-renewable' energy sources.[5]

Petroleum was shipped to Sydney from several sources, predominantly Bass Strait off the coast of Victoria, the Middle East and Southeast Asia. Most of it arrived as crude oil and was refined within the SSD, at Kurnell and Clyde, into a variety of products. Some of these then left the SSD by road, rail and pipeline for distribution elsewhere in NSW (EnANSW 1986d,7). All of the natural gas used in Sydney arrived by a single 1300 km long pipeline from the Cooper Basin in South Australia.

Sydney is one of the few large cities in the world to have been established, entirely by chance, over a major fossil fuel deposit. What has come to be known as the Sydney-Gunnedah coal basin extends in a radius of some 100 km fom the SSD. In 1986 none of this coal was mined from directly beneath the city, and only a small proportion of the coal mined elsewhere in NSW was transported to the city in original form. Most of the coal-derived energy flowing into Sydney was in the form of electricity, entering the urban area through high-voltage transmission circuits at some 18 points.[6]

The electricity system was the most versatile in the range of primary resources it utilised. Apart from coal energy it also transmitted to Sydney renewable energy from running water, collected at various locations throughout the state with suitable topography and hydrology. There was also some small scale electricity generation within the SSD itself, using some of the fossil fuel brought to the city in primary form.

The techno-energy entering the urban area was distributed to points of 'end use': solid and liquid fuels by the freight transportation system, gas by a grid of pipelines and electricity by a grid of cables. At these points it was converted by specialised equipment to energy forms such as heat, light and power. These forms had social and economic significance, in that they were valued and traded for their ability to enhance amenity or as inputs to production processes. They may therefore generally be described as 'energy services'.

The transformation of energy into desired services was necessarily accompanied by forms not desired, such as noise or chemical transformations (eg smog), and ultimately low grade heat. The residual heat production of the urban area was a rough indication of the scale of its techno-energy system. It has been estimated that in 1970 the heat generated by techno-energy transformations in the SSD was eqivalent to 1% of the annual incoming solar radiation, and in the City of Sydney LGA it was over 25% (Kalma et al 1972,138).[7]

## Fuel Consumption in the Sydney Techno-Energy System

The total energy delivered to consumers in Sydney and in the rest of NSW in 1986 is given in Table 1.1, disaggregated by energy type and end use sector. The NSW totals for fuels other than electricity and gas, for which more detailed data are available elsewhere, are taken from Energy Authority statistics (EnANSW 1987,68). It is possible to calculate the quantity of energy delivered to metropolitan users from the annual reports of the Sydney utilities, including the Sydney County Council (SCC), Prospect County Council (PCC) and the Australian Gas Light Company (AGL), supplemented by those of the Joint Coal Board (JCB) and Electricity Supply Association of Australia (ESAA).[8]

Electricity was generated and transmitted throughout NSW by the Electricity Commission of NSW (ECNSW), and delivered to consumers by 26 local supply authorities, of which the two largest served Sydney. The SCC served the eastern, coastal part of the SSD, and the PCC the western part.[9] The boundaries of the two county councils are shown in Figure 1.2. The two councils supplied a total of about 19,050 GWh of electricity to their customers in 1986, with an energy content of 71 PJ, calling on a total of 235 PJ of primary energy in the form of coal and equivalent hydro resources.[10] In addition, some 2.4 PJ of electricity was used by the Sydney electrified rail system.[11]

Sydney was supplied with gas by AGL Sydney Ltd (AGLS) a subsidiary of AGL. Natural gas from Moomba in northeast South Australia was transported by a federal government instrumentality, The Pipeline Authority, and entered the Sydney distribution system at Plumpton and Horsley Park. Unlike electricity, where virtually every buildng in the SSD was connected to the distribution grid, only about 32% of Sydney dwellings were connected to gas, and a further 25% were on a line of mains and so readily connectable (EnANSW 1987b,58). The total energy content of the gas sold to consumers in the SSD in 1986 was 48.2 PJ. A further 5.2 PJ, or 11.0% of sales, was lost in distribution or used in reprocessing works.[12]

The consumption of petroleum fuels in the SSD is considerably more difficult to estimate than that of gas or electricity. There were several suppliers, each with distribution areas extending well beyond the SSD. The 'Sydney Marketing Area' covered most of the area and over 92% of the population of the entire state (EnANSW 1986d,7). A further complication was that, unlike energy used in stationary applications, the use of transport fuels may be considerably removed, in space and time, from the point of sale. Nevertheless it is possible to aggregate consumption of petroleum fuels in the SSD from other sources, and it is estimated that the total petroleum products use for all stationary applications in 1986 was about 40 PJ.[13]

Coal use within the SSD has been obtained directly from JCB statistics. Excluding electricity generation by ECNSW stations within the northern boundary, some 7 PJ of coal was used: about one sixth of it by commercial users, mainly hospitals, and the rest by industrial users, mainly the chemical and brick industries. Other energy forms used in the NSW techno-energy system included direct solar radiation, wood and bagasse (the fibrous residue of sugar cane). Wood consumption within the SSD in 1986 is estimated at less than 2 PJ.[14] In 1986 nearly 3% of Sydney households had solar water heaters, almost all of them boosted with electricity (ABS 1987a,15). On the assumption that solar radiation displaces about 60% of the 10.9 GJ per annum which would otherwise be required by a typical all-electric water heater (EnANSW 1987b, 33), the solar contribution within the SSD was less than 0.2 PJ.

Table 1.1 indicates that petroleum fuels made up over 57% of all energy delivered to users in the SSD in 1986, electricity over 23% and gas nearly 11%. It would however be misleading to conclude that oil was the dominant fuel in the Sydney techno-energy system. The balance of fuels is better indicated by primary rather than delivered energy: that is, including losses incurred in transformations of primary fuels to secondary energy forms and in their distribution. Table 1.2 shows the primary energy resources contributing to the Sydney energy system in 1986. It reveals that in fact coal, not oil, was Sydney's dominant primary energy source. It supplied 48% of the primary energy, though barely 4% of the coal was actually transported to Sydney in solid form. Oil supplied about 38% of Sydney's primary energy and natural gas nearly 11%. Renewable energy resources, including hydro-electricity, wood and solar, accounted for less than 4%.

The 483 PJ of primary energy utilised by the Sydney techno-energy system may be compared with the scale of the local bio- and geo- energy systems. The metabolic energy required per person is approximately 3200 kilo-calories per day (Kalma 1972,137). The estimated annual bio-energy requirement of Sydney's human population was therefore about 17 PJ, or 3.4% of the energy requirement the techno-energy system. The mean incident solar radiation for the Sydney area is about 6.13 PJ/sq km annually (ibid,138). The renewable geo-energy incident on the SSD from direct solar radiation alone was therefore 76,700 PJ, or 165 times the energy content of the fossil fuels utilised by the Sydney techno-energy system in 1986.

## Indicators of Electrification

Neither the scale of the techno-energy system nor the balance of energy forms within it was static. Table 1.2 shows that Sydney primary energy requirement increased 62% over the period 1971 to 1986. This was caused less by growth in delivered energy use per capita (which according to Table 1.3 increased only 27%), than by a shift in the energy balance towards electricity. Table 1.2 shows that the electricity component of the city's primary energy requirement increased from 33.6% in 1971 to 46.2% in 1986. This was accompanied by a significant change in the form in which coal energy entered the urban area. In 1971 nearly 28% came from coal physically transported to Sydney for distribution or for conversion to gas, but in 1986 barely 4% came in solid form, and coal gassification had been replaced entirely by natural gas.

Similar changes took place in the NSW energy system outside Sydney. Table 1.3 shows a sharp increase in NSW electrification between 1971 and 1986. Electricity increased its share from 15% to 24% of energy delivered in Sydney, and from 7% to 15% in the rest of the state. Gas was the only other fuel to increase its share, from 5% to 16% in Sydney, and from 0.4% to 9% in the rest of NSW, largely displacing oil from non-transport uses. To the extent that a high proportion of reticulated energy distribution is a historical feature of urban energy systems, the rest of NSW in 1986 was as "urban" as Sydney in 1971. Reticulated gas and electricity supplied 32% of Sydney's non-transport energy in 1971, and 72% in 1986 (10% and 38% respectively in the rest of the state).[15] While the geographical varations within the NSW energy system were blurring over time, there remained major differences in the spatial density of energy use. Table 1.3 shows that electricity consumption per sq km in the SSD was nearly 65 times that in the rest of NSW, and gas consumption nearly 17 times.

Several features distinguished the NSW non-transport energy system from those of other Australian states.[14] Table 1.4 demonstrates that in most states a single resource dominated the supply of non-transport energy: in NSW and Queensland it was black coal, in SA and WA natural gas and in Tasmania hydro-electricity. Victoria was the one state with a relatively balanced use of two primary resources, brown coal and natural gas. In most states only a part of the energy obtained from the primary resource was delivered to consumers in the form of electricity. A considerable proportion of the coal mined in NSW was used in the iron and steel industry, and about twice as much coal was exported as used within the state. Only in Tasmania could the state's major energy resource be distributed in no form other than electricity. Consequently the Tasmanian energy system was far more electrified than any of the mainland states.

In 1986 NSW was the most highly electrified of the mainland states in terms of both total and per capita electricity consumption, as shown in table 1.5. Much of the variation between states was due to differences in the pattern of industrialisation and economic activity. However, there were also differences in ethe residential sector, despite the fact that the demand for household energy services was relatively homogenous, with virtually all Australian households connected to electricity and having similar appliance stocks.[17] Table 1.6 shows that Hobart was alone among the capitals in having no reticulated gas and a very high proportion of households using oil and solid fuels. Sydney and Brisbane were the most highly electrified in terms of the proportion of households reliant solely on electricity (50% and 58% respectively) and the proportion of reticulated energy supplied by electricity (83% and 91%). At the other extreme was Melbourne, with gas connected to 81% of its dwellings and supplying 70% of household reticulated energy. Melbourne households used three times as much gas as those in Sydney.[18]

NSW had, in 1986, the most electricity-intensive energy system of the mainland Australian states. Sydney was the most highly electrified part of it, and had become more so in the previous 15 years. The significance of the electricity sector of the energy system was reflected in the magnitude of capital investment in it. Unlike the USA, where three quarters of all electricity for public sale is generated by investor-owned utilities (Munson 1985,220), the electricity supply system in NSW, as in other Australian states, was entirely publicly owned. It represented a total capital investment of nearly $ 8900 million at the end of 1985. Over three quarters of this was made up by ECNSW generation and transmission assets and the rest by the county councils' distribution systems. On every financial indicator the ECNSW far exceeded in scale the next largest public enterprise, the State Rail Authority (see Table 1.7).[19] This of course represented only the public proportion of the total investment in electricity: it excluded the private investment in wiring, appliances and electrical equipment which are as essential to the supply of electrical energy services as power stations.

How had the NSW and Sydney energy systems come to develop their particular physical and organisational structures? What factors accounted for their magnitude and degree of electrification? Were there limits to the demand for energy, and for electricity in particular? These questions are central to understanding what had become, by 1986, the single most capital and resource-intensive activity in the public sector of the NSW economy.

**FIGURE 1.1**
**PRIMARY ENERGY COLLECTION BY THE SYDNEY ENERGY SYSTEM**
**1986**

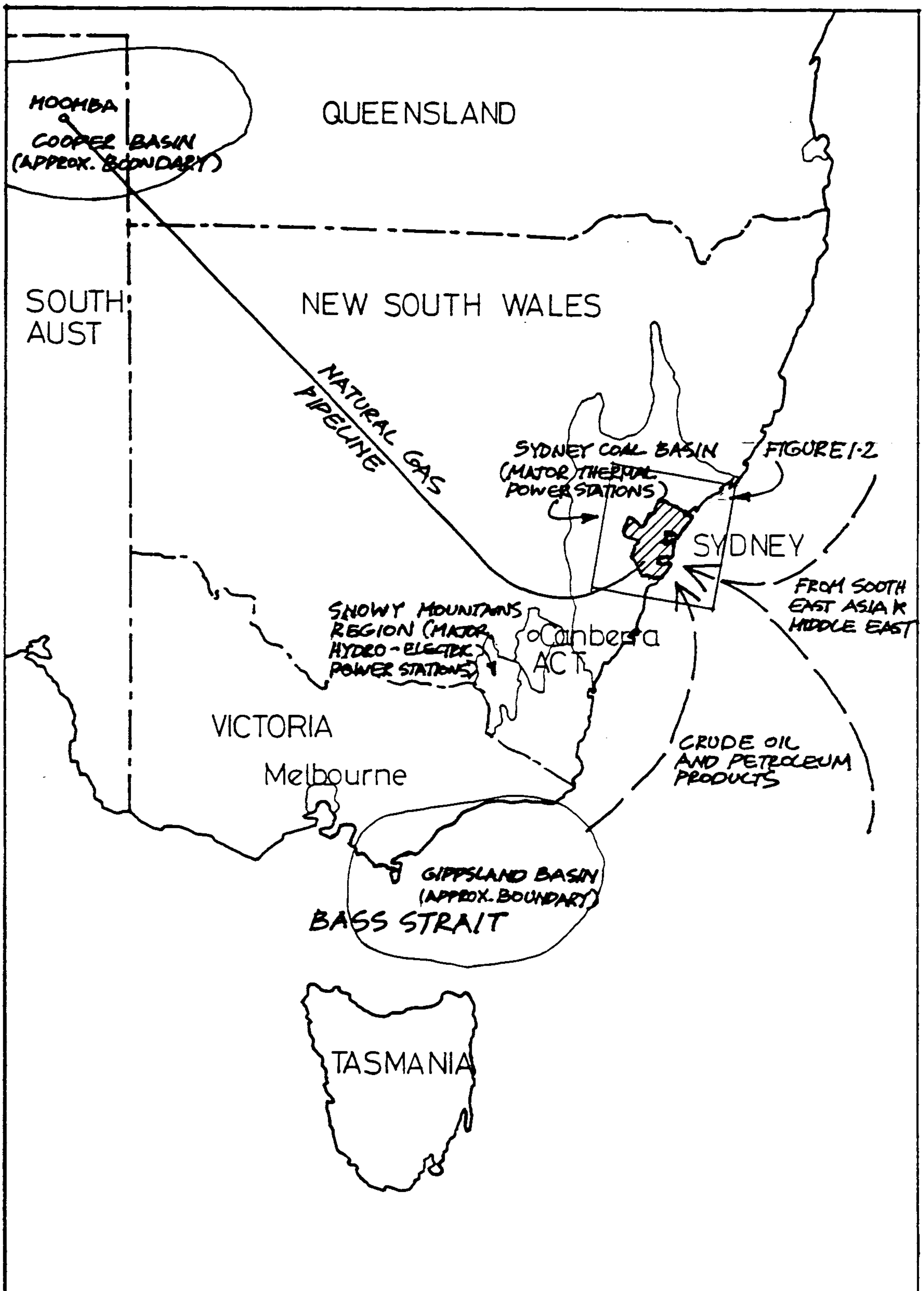


FIGURE 1.2
BOUNDARIES OF THE SYDNEY STATISTICAL DIVISION AND RETICULATED ENERGY SUPPLY ORGANISATIONS
1986

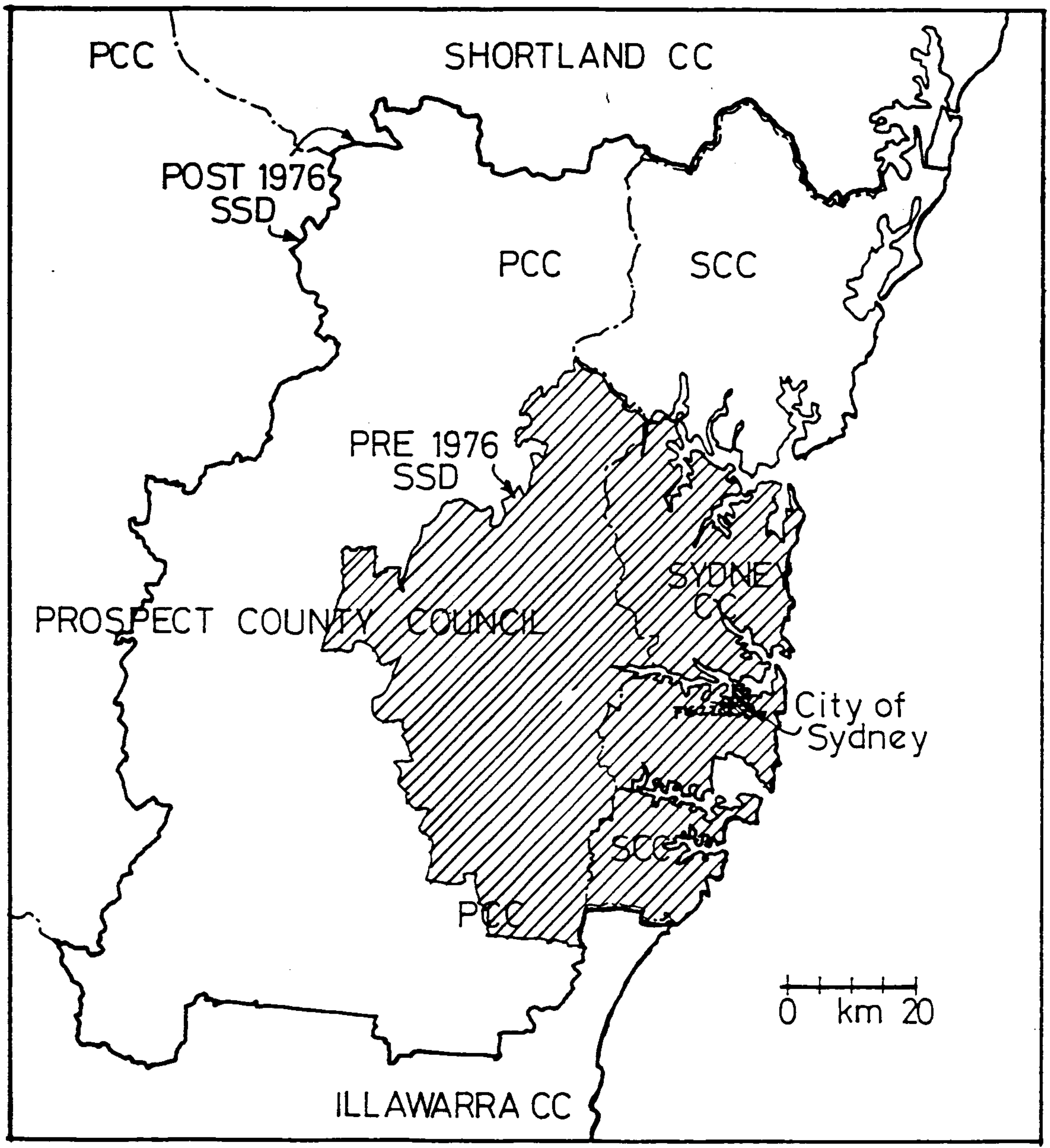


TABLE 1.1
DELIVERED AND PRIMARY ENERGY USE BY CONSUMPTION SECTOR
SYDNEY AND NSW
1986

| ENERGY | PJ Delivered by sector | | | | TOTAL | TOTAL | Sydney % of NSW Deliv. Energy | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| TYPE | RESID | COMM | INDUS | TRANS | DELIV | PRIM(a) | RESID | COMM | INDUS | TRANS | TOTAL |
| ELECT | 30.7 | 12.5 | 25.4 | 2.4 | 71.0 | 239.2 | 60.9 | 58.9 | 38.4 | 100.0 | 50.6 |
| en/sec(b) | 74.6 | 57.6 | 24.7 | 1.7 | 23.5 | 49.5 | | | | | |
| sec/en(c) | 43.2 | 17.6 | 35.7 | 3.3 | 100 | | | | | | |
| (b) | | | | | | | | | | | |
| GAS | 6.6 | 6.0 | 35.7 | 0.0 | 48.3 | 52.1 | 89.1 | 89.5 | 47.3 | | 53.9 |
| en/sec | 16.0 | 27.6 | 34.8 | 0.0 | 16.0 | 10.7 | | | | | |
| sec/en | 13.6 | 12.4 | 73.9 | 0.0 | 100 | | | | | | |
| OIL | 2.0 | 2.0 | 35.6 | 133.2 | 172.8 | 181.4 | 50.0 | 25.0 | 79.1 | 44.8 | 48.8 |
| en/sec | 4.8 | 9.2 | 34.7 | 98.2 | 57.4 | 37.5 | | | | | |
| sec/en | 1.1 | 1.1 | 20.6 | 77.0 | 100 | | | | | | |
| COAL | 0.0 | 1.2 | 5.8 | 0.0 | 7.0 | 8.4 | 0.0 | 40.0 | 3.8 | | 4.5 |
| en/sec | 0.0 | 5.5 | 5.6 | 0.0 | 2.3 | 1.7 | | | | | |
| sec/en | 0.0 | 17.1 | 82.8 | 0.0 | 100 | | | | | | |
| OTHER(d) | 1.8 | 0.0 | 0.0 | 0.0 | 1.8 | 1.8 | 20.0 | | 0.0 | | 11.2 |
| en/sec | 4.3 | 0.0 | 0.0 | 0.0 | 0.5 | 0.3 | | | | | |
| sec/en | 100.0 | 0.0 | 0.0 | 0.0 | 100 | | | | | | |
| TOT | 41.1 | 21.7 | 102.5 | 135.6 | 300.9 | 483.0 | 57.2 | 55.7 | 29.8 | 45.2 | 39.9 |
| sec/en | 13.6 | 7.2 | 34.0 | 45.0 | 100 | | | | | | |

(Sources: EnANSW 1986, 1987, 1985a, JCB personal communication, BRE 1987, ABS 1987a).

a. Assumed multipliers for converting Delivered to Primary energy: Electricity 3.37, Gas 1.08, Oil 1.05, Coal 1.20, Other 1.00
b. energy/sector: percentage of that sector's energy use supplied by that energy form: adds to 100 vertically; eg 74.6% of residential sector delivered energy was supplied by electricity.
c. sector/energy: percentage of that energy form used by that sector: adds to 100 horizontally; eg residential sector accounted for 43.2% of electricity use.
d. Mainly firewood, direct solar and bagasse (dried residue of sugar cane used as mill fuel in the north coast sugar growing region of NSW). No bagasse use is assigned to Sydney.

**TABLE 1.2**
**PRIMARY ENERGY SOURCES**
**SYDNEY**
**1971 AND 1986**

| ENERGY SOURCE | 1971 | | 1986 | |
|---|---|---|---|---|
| | PJ | % | PJ | % |
| COAL Electricity | 100.1 | 33.7 | 222.5 | 46.1 |
| Gas | 7.5 | 2.5 | - | - |
| Direct to users | 30.7 | 10.3 | 8.5 | 1.8 |
| TOTAL COAL | 138.3 | 46.5 | 231.0 | 47.8 |
| OIL Gas | 9.8 | 3.3 | - | - |
| Direct to users | 143.2 | 48.2 | 181.4 | 37.6 |
| NATURAL GAS | - | - | 52.1 | 10.8 |
| TOTAL OIL & NAT GAS | 153.0 | 51.5 | 233.5 | 48.3 |
| HYDRO Electricity | 5.7 | 1.9 | 16.7 | 3.5 |
| OTHER | 0.1 | <0.1 | 1.8 | 0.4 |
| TOTAL RENEWABLES | 5.8 | 1.9 | 18.5 | 3.8 |
| TOTAL PRIMARY ENERGY | 297.1 | 100.0 | 483.0 | 100.0 |

(Sources: 1971 data from derived from Kalma 1976, 1986 data derived from Table 1.1; hydro proportion of 1986 electricity generation from ECNSW 1986).

TABLE 1.3
ENERGY CONSUMPTION BY FUEL, END USE, PER CAPITA AND PER AREA
SYDNEY AND REST OF NSW
1971 AND 1986

| | | 1971 SYDNEY (a) | 1971 REST OF NSW | 1971 TOTAL NSW | 1986 SYDNEY (a) | 1986 REST OF NSW | 1986 TOTAL NSW |
|---|---|---|---|---|---|---|---|
| POP ('000) | | 2935.9 | 1665.3 | 4601.2 | 3430.6 | 2046.3 | 5476.9 |
| HH ('000) | | 892.2 | 472.3 | 1364.5 | 1119.5 | 625.0 | 1744.5 |
| AREA (Km2) | | 12507 | 788921 | 801428 | 12507 | 788921 | 801428 |
| PERSONS/HH | | 3.2 | 3.5 | 3.3 | 3.0 | 3.2 | 3.1 |
| /km2 | | 234.7 | 2.1 | 5.7 | 274.2 | 2.5 | 6.8 |
| PJ | RES | 21.0 | 19.0 | 40.0 | 41.1 | 30.7 | 71.8 |
| | COM | 20.4 | 17.6 | 38.0 | 21.7 | 17.2 | 38.9 |
| | IND | 89.1 | 277.9 | 367.0 | 102.5 | 241.0 | 343.5 |
| | TRA | 73.2 | 115.8 | 189.0 | 135.6 | 163.8 | 299.4 |
| | TOT | 203.7 | 430.3 | 634.0 | 300.9 | 452.7 | 753.6 |
| GJ/CAP | RES | 7.1 | 11.4 | 8.6 | 11.9 | 15.0 | 13.1 |
| | COM | 6.9 | 10.5 | 8.2 | 6.3 | 8.4 | 7.1 |
| | IND | 30.3 | 166.8 | 79.7 | 29.8 | 117.7 | 62.7 |
| | TRA | 24.9 | 69.5 | 41.0 | 39.5 | 80.0 | 54.6 |
| | TOT | 69.3 | 258.3 | 137.7 | 87.7 | 221.2 | 137.5 |
| GJ/km2 | RES | 1679.0 | 24.0 | 49.9 | 3286.1 | 38.9 | 89.5 |
| | COM | 1631.0 | 22.3 | 47.4 | 1735.0 | 21.8 | 48.5 |
| | IND | 7124.0 | 352.2 | 457.9 | 8195.4 | 305.4 | 428.6 |
| | TRA | 5852.7 | 146.7 | 235.8 | 10841.9 | 207.6 | 373.5 |
| | TOT | 16286.8 | 545.4 | 791.0 | 24058.5 | 573.7 | 940.3 |
| GJ/HH | RES | 23.5 | 40.2 | 29.3 | 36.7 | 49.1 | 41.1 |
| PJ | ELE | 31.3 | 29.7 | 61.0 | 71.0 | 69.1 | 140.1 |
| | GAS | 10.3 | 1.7 | 12.0 | 48.3 | 41.2 | 89.5 |
| | OIL | 136.4 | 149.6 | 286.0 | 172.8 | 181.2 | 354.0 |
| | COA | 25.6 | 245.4 | 271.0 | 7.0 | 147.0 | 154.0 |
| | OTH | 0.1 | 3.9 | 4.0 | 1.8 | 14.6 | 16.0 |
| | TOT | 203.7 | 430.3 | 634.0 | 300.9 | 452.7 | 753.6 |
| GJ/CAP | ELE | 10.6 | 17.8 | 13.2 | 20.6 | 33.7 | 25.5 |
| | GAS | 3.5 | 1.0 | 2.6 | 14.0 | 20.1 | 16.3 |
| | OIL | 46.4 | 89.8 | 62.1 | 50.3 | 88.5 | 64.6 |
| | COA | 8.7 | 147.3 | 58.8 | 2.0 | 71.8 | 28.1 |
| | OTH | 0.0 | 2.3 | 0.8 | 0.5 | 6.9 | 2.9 |
| | TOT | 69.3 | 258.3 | 137.7 | 87.7 | 221.2 | 137.5 |
| GJ/km2 | ELE | 2502.5 | 37.6 | 76.1 | 5676.8 | 87.5 | 174.8 |
| | GAS | 823.5 | 2.1 | 14.9 | 3861.8 | 52.2 | 111.6 |
| | OIL | 10905.8 | 189.6 | 356.8 | 13816.2 | 229.6 | 441.7 |
| | COA | 2046.8 | 311.0 | 338.1 | 559.6 | 186.3 | 192.1 |
| | OTH | 7.9 | 4.9 | 4.9 | 143.9 | 17.9 | 19.9 |
| | TOT | 16286.8 | 545.4 | 791.0 | 24058.5 | 573.8 | 940.3 |

(Sources: see Table 1.1)
a. 1986 Sydney Statistical Division, as defined by ABS.

**TABLE 1.4**
**ENERGY CONSUMPTION BY PRIMARY FUEL SOURCE**
**AUSTRALIAN STATES**
**1984/5**

| FUEL SOURCE | NSW PJ (%) | VIC PJ (%) | QLD PJ (%) | SA PJ (%) | WA PJ (%) | TAS PJ (%) |
|---|---|---|---|---|---|---|
| BLACK COAL | 560.1 (51.1) | 0.1 (0) | 262.9 (43.8) | 54.8 (19.4) | 82.4 (24.0) | 8.1 (9.8) |
| BROWN COAL | - | 369.2 (38.7) | - | - | - | - |
| WOOD, WOODWASTE | 22.3 (2.0) | 29.4 (3.1) | 7.3 (1.2) | 7.6 (2.7) | 8.5 (2.5) | 8.3 (10.0) |
| BAGASSE | 4.1 (0.4) | - | 68.8 (11.5) | - | - | - |
| PETROLEUM PRODUCTS | 403.0 (36.8) | 329.3 (34.5) | 239.9 (40.0) | 100.7 (35.6) | 177.0 (51.6) | 37.2 (45.0) |
| NATURAL GAS | 85.6 (7.8) | 224.2 (23.5) | 18.7 (3.1) | 119.4 (42.2) | 73.9 (21.6) | - |
| SOLAR | 0.6 (0) | - | - | 0.1 (0) | 1.1 (0.3) | - |
| HYDRO | 20.5 (1.9) | 2.8 (0.3) | 2.2 (0.4) | - | - | 29.0 (35.1) |
| TOTAL | 1096.2 | 955.0 | 599.8 | 282.6 | 342.9 | 82.6 |

(Source: BRE 1987, Tables E3 to E7. Minor discrepancies in the totals of the source tables, probably reflecting changes in stocks of solid fuels, are ignored).

TABLE 1.5
ELECTRICITY CONSUMPTION PER CAPITA AND PRICE INDICES
BY STATES AND CAPITALS
1985/6

| | NSW | VIC | QLD | SA | WA | TAS |
|---|---|---|---|---|---|---|
| KwH/CAPITA | | | | | | |
| Residential | 2430 | 1960 | 2000 | 2040 | 1450 | 3860 |
| Other | 4340 | 3400 | 4430 | 2980 | 2760 | 13300 |
| Total | 6770 | 5360 | 6430 | 5020 | 4210 | 17160 |
| CAPITAL CITY PRICE INDEX | | | | | | |
| Residential | 100 | 119 | 127 | 121 | 158 | 124 |
| Commercial | 100 | 123 | 105 | 111 | 114 | 88 |
| Industrial LV | 100 | 72 | 83 | 101 | 128 | 75 |
| Industrial HV | 100 | 82 | 110 | 124 | 128 | 105 |

(Sources: Electricity sales ESAA 1985/6
Price indices for July 1986 from SECV 1985/6,52)

TABLE 1.6
MAIN FEATURES OF HOUSEHOLD RETICULATED ENERGY USE
BY STATE CAPITALS
1986

| | Sydney | Melbourne | Brisbane | Adelaide | Perth | Hobart |
|---|---|---|---|---|---|---|
| % HOUSEHOLDS USING: | | | | | | |
| Gas | 29.5 | 80.9 | 20.3 | 61.6 | 44.5 | - |
| Other fuel | 20.9 | 8.5 | 21.4 | 21.8 | 39.7 | 70.3 |
| Electricity only | 49.6 | 10.6 | 58.3 | 16.6 | 15.8 | 29.7 |
| GJ/HH USING: | | | | | | |
| Electricity | 25.0 | 19.8 | 21.7 | 20.1 | 16.5 | 34.4 |
| Gas | 17.3 | 56.7 | 11.0 | 27.3 | 17.6 | - |
| GJ/CAP RETICULATED | | | | | | |
| Electricity | 8.0 | 6.2 | 6.9 | 6.9 | 5.4 | 11.4 |
| Gas | 1.6 | 14.5 | 0.7 | 5.8 | 2.5 | - |
| Total Reticulated | 9.6 | 20.7 | 8.6 | 12.7 | 7.9 | 11.4 |
| % Electricity | 83 | 30 | 91 | 54 | 68 | 100 |
| $/GJ | | | | | | |
| Electricity | 18.4 | 21.0 | 23.1 | 21.9 | 27.5 | 16.6 |
| Gas | 9.4 | 6.2 | 14.0 | 7.9 | 10.9 | - |
| % HOUSEHOLDS WITH: | | | | | | |
| Roof Insulation | 37.3 | 59.8 | 14.2 | 65.2 | 45.7 | 49.9 |
| Air Conditioning | 29.2 | 38.9 | 13.2 | 66.2 | 37.9 | 0.1 |

(Sources: ABS 1987a, 1987b, 1988a)

TABLE 1.7
CAPITAL INVESTMENT IN PUBLIC ELECTRICITY SUPPLY AND RAILWAYS
NSW
1985/6

| | ELECTRICITY (Dec 1985) $ m | RAILWAYS (Jun 1986) $ m |
|---|---|---|
| COUNTY COUNCILS: | | |
| Distribution | 2005 | |
| ECNSW | | |
| Transmission | 826 | |
| Thermal power stations | 3616 | |
| Hydro power stations | 44 | |
| Other fixed assets | 677 | |
| TOTAL ASSETS IN SERVICE | 7166 | |
| Under construction | | |
| County Councils | 35 | |
| ECNSW | 1694 | |
| TOTAL FIXED ASSETS | 8895 | 3180 |
| TOTAL ASSETS | | 4221 |
| Capital works 1985/6 | 833 | 422 |
| Revenue 1985/6 | 2921 | 1082 |
| EMPLOYEES | | |
| County councils | 17600 | |
| ECNSW | 11000 | |
| TOTAL EMPLOYEES | 28600 | 41400 |

(Sources: EnANSW/EFS 1985,5
Budget Information, NSW, Vol 2, 1986/7,99
SRA 1985/6)

Capital investment in Commonwealth-controlled Snowy Mountains Scheme not included, although about half of its electricity output was supplied to NSW.

## 1.2 MODELS OF ELECTRIFICATION

The term 'electrification' describes the process by which techno-energy systems evolve to an electricity-intensive state. The means for distributing the energy in fossil fuel via an electric current, and then applying it to uses for which the original fuel was not well suited, first became commercially available about a century ago. Since then, electrification has come to be associated with increasing industrialisation in production and increasing urbanisation in human settlements. The association is mutually reinforcing: as an energy distribution medium electricity is best suited to densely settled areas, and it excels at the flexible power applications required in modern manufacturing.

With the export of technical knowledge and actual equipment from the major centres of Europe and North America, electrification took a roughly parallel course throughout the developed world. Global trends in electro-technology interacting with local physical and political conditions produced many local electricity systems. Simplified representations, or models, of these processes and interactions assist in their analysis. The construction of models - the selection of important elements and the characterisation of the relationships between them - is a largely pragmatic exercise. The test of usefulness for a model of the electrification of the Sydney energy system is its ability to account for the present condition of the system which it represents, to successfully predict changes in it, and perhaps ultimately to assist in its management.

### General Models of Electrification

No general political, spatial, historical or technological paradigm can account completely for the electrification of the Sydney energy system, because by definition such a model must be local and specific. Since electrification is a universal feature of developed urban energy systems one might expect to draw on a large body of local case studies and general analyses. This is not the case. While there are many histories of electrical engineering and longitudinal studies of the impact of electro-technology on industry, and economic and engineering models of short term change in energy and electricity systems constitute the major part of the literature of utility planning, there are few models of the historic process of electrification as it occurs in a specific urban system. However many elements and relationships may be adapted from more general analyses of change in energy, technological and economic systems.

Energy flows are clearly fundamental in explaining the behaviour and disposition of matter within the entire universe, as well as the relationships of organisms within the earth's biosphere. All energy processes, whether occuring in nature or in a machine, conform to the known physical laws of thermodynamics, the first of which states that the quantity of energy is conserved through any transformation (Ubbelohde 1963,209). This has tempted scientists and engineers to construct universal energy models in terms borrowed from the physical or biological sciences, and which deal uneasily with the energy needs of human society somewhere in the transition from astronomical to sub-atomic scale. Proponents of the view that the functioning and historical development of society are governed by the same natural laws as all other energy systems have included Soddy (1912) and Odum (1971).

General energy system models are useful for establishing and quantifying the relationships between different forms of energy, including the parameters of exchange between the geo-, bio- and techno-energy systems. Nevertheless their scope in time and space is too broad to capture the details of change at the level of a local urban system. Electricity system planning and management models on the other hand are too fine in their definition of time, and often completely abstracted from space (see for example Turvey 1968).

Several technological and urban historians have developed models of historical succession in energy technologies, including Marchetti (1987). Some deal explicitly with their relationship to urbanisation and industrialisation ,notably in Daniels and Rose (1982):

> "The transition from wood and waterpower to coal was a major turning point in the material life of the United States...Coal helped to accelerate the process of large-scale manufacturing and became the essential fuel for heat and light in the major cities. Coal was indeed an urban fuel" (Melosi 1982,65).

The general approach has been fleshed out by quantitative data on energy use at the national level (Morrison 1982) and case studies of utility formation in specific American cities (eg Rose and Clark 1979, Rose 1984).

One of the few historians to study electrification as both a specific local phenomenon and a general mechanism of technological change is Hughes, who describes the development of central electricity systems in Europe and the USA between 1880 and 1930 within the framework of a

> "...model of system formation and growth ...[which]...may prove relevant not only to the history of power systems but to history focussed on technology generally" (Hughes 1983,461).

Hughes documents the contribution of local factors, including political, financial and economic structure, to variations in the electrification of Britain, the USA and Germany. While his model emphasises the links between capital, government and technological entrepreneurs, it contains little analysis of the crucial relationship between supply technologies and end use.

Although general historical models of change in energy and electricity systems provide some guidance for characterising the electrification of the Sydney energy system, no one of them incorporates all of the spatial, political, resource and demand elements apparent from an analysis of the system in 1986.

**The Dimension of Space**

A principal function of the modern techno-energy system is to transport energy from remote primary fuel sources to the point of energy demand. The effect of relative location is treated in detail by Manners in *The Geography of Energy* (1964):

> "What, then are the major forces which influence the geography of energy? Basic to all explanations is the distribution of *energy resources* about the face of the globe...The geography of the world's oil and natural gas fields, the suitability of sites for the generation of hydro-electricity, and the pattern of the world's coal deposits clearly have a fundamental relevance to the spatial patterns of energy production, trade and consumption" (Manners 1964,25, original emphasis).

Although resource geography is fundamentally important, it alone cannot account for the observed energy system development without reference to specific economic, technological and political conditions.

Sydney's first techno-energy systems utilised the available bio-energy (eg timber fuel, human and animal power) and geo-energy (wind and water power) resources. The high quality coal resources of the Hunter and Illawarra districts were discovered early in the town's life but did not at first make much impact on its energy system, because local timber was much cheaper. With improvements in the technology of coal extraction, transport and utilisation, the costs per unit of coal energy declined while the costs of timber increased as the nearest supplies became exhausted. From the 1840s to the 1940s the Sydney techno-energy system was fuelled increasingly by coal brought from the Hunter and Illawarra regions by rail or ship, which were themselves mainly coal powered.

The energy systems of other Australian capital cities were also affected by their spatial relationship to the NSW coalfields. Given the costs of long-distance transportation, the frequent disruptions in supply and the price manipulations characteristic of the NSW coal industry, the other states took political action to develop alternative energy resources where possible. NSW coal remained the most common gasmaking fuel in the south-eastern states until the 1950s, but its use in thermal electricity generation was easier to substitute.

The economics of extracting the energy from LaTrobe Valley brown coal and transporting it to Melbourne was the key issue in the Victorian energy system from the 1910s. The low energy density of the fuel economically precluded its physical carriage to Melbourne, about the same distance by land as from Newcastle to Sydney by sea. With the political and financial support of the Victorian government, techniques were developed for the transmission of brown coal energy to Melbourne in the secondary forms of briquettes and electricity in the 1920s (Edwards 1969,82-91) and as gas in the 1950s (Proudley 1987,216).

By contrast, coal gas for the Sydney market was never manufactured outside the city, and electricity did not become a medium of energy transport from the coalfields until the 1950s: black coal was physically transported to Sydney and then distributed to the various energy markets within the city in solid form, as coal gas or as electricity. Thus the interaction of politics with spatial economics made electricity an important means of energy transmission into Melbourne three decades before it filled that role in Sydney.

Until the 1950s, electricity served Sydney and most other NSW towns as a medium of local distribution for the energy in transported coal, rather than of long distance energy transmission, as in Victoria and Tasmania. This spatial constraint established NSW electricity supply within the ambit of local government politics. The NSW state government did not intervene significantly in the development of electricity supply until 1945, whereas generation became a state government concern in Tasmania as early as 1914 and in Victoria in 1919. The accidents of resource geography influenced not only the physical form of the electricity system in those states but also its monolithic organisational structure and its relationship to government (Saddler 1981,51).

Within cities, the distribution of energy in discrete form (solids or liquids) is subject to the same spatial influences as any other distributed goods. There is a hierarchy of producers, retailers and intermediate wholesalers, the relative location of which has been studied by geographers (eg Morrill 1970,76). Dixon's (1972) analysis of the development of petrol distribution in Sydney and other Australian cities documents the interaction of spatial influence, packaging and transportation technology, and commercial competition between suppliers.

The high capital investment required for a permanent system of pipes or wires connecting the energy producer with each consumer is usually economic only in areas with a high density of energy demand. All else being equal, large energy consumers in a compact area represent the most economic load for electricity, gas or hydraulic power distribution. Consequently, the reticulated energy systems constructed by private, profit-seeking enterprises have historically originated in the commercial centres of large cities. They then expanded to industrial areas with a lower density but larger energy consumers, and then to older urban residential areas, with a high density of small consumers. The suburbanisation characteristic of the growth of Sydney in the present century led to a low density of low energy consumers, the least economic type of load for a energy reticulation. The balance of land uses and consumer densities served by a reticulated energy system has a strong effect on its financial viability. In recognition of this, NSW governments found it necessary to alter the boundaries of Sydney's several electricity distribution authorities on a number of occasions, most recently in 1980. Suburbanisation also contributed to the postwar decline of the Sydney gas system, which, being privately owned, could not draw so freely on public resources for its expansion. As a result gas was unavailable as an alternative to electricity in the most rapidly growing and least dense parts of the city in the 1950s and 1960s.

The spatial relationship between electricity systems was also a factor in their development. During the 1940s several separate electricity networks in and around Sydney were interconnected to achieve economies of scale in production and distribution. Once the systems of the major urban centres were unified, they were extended into rural areas below the economic threshhold of load density, largely at the insistence of state governments, a development common in public electricity suppliy throughout the world (Manners 1964, 118). This gave rise to a system of spatially-determined transfers and subsidies which became one of the hallmarks of electrification in NSW.

### The Dimension of Time

Time is an essential dimension of energy systems. The short term rate of energy transformation usually limits the system more than the quantity of energy required in the longer term. Mumford recognises this in *The City in History*:

> "Living organisms can use only limited amounts of energy. 'Too much' or 'too little' is equally fatal to organic existence. Organisms, societies, human persons, not least cities, are delicate devices for regulating energy and putting it to the service of life" (Mumford 1961,650).

The complete and permanent de-energisation of the city has often been used in modern speculative fiction and film as a metaphor for the collapse of urban society.[20] So has the uncontrolled energy release of the thermonuclear explosion. The first nuclear bombs destroyed entire cities, yet controlled thermonuclear reactions are now used throughout the world to generate electricity for cities.[21] The critical difference is in the rate of energy release.

Rates of energy production and consumption must be managed to some extent in all techno-energy systems, however simple. The members of rural households typically cut wood over several months in summer, and stacked it in sufficient quantity to last the winter season of peak consumption. Time management becomes especially important in reticulated energy systems in which the processes of production and consumption are continuous and physically linked. In the nineteenth century most of the demand for gas was created by the market for night time lighting. This peak was met by supplementing night time production with gas produced during the day and stored in holders. The major, and often the only demand on early electricity generating stations was also for night time lighting. Battery storage of surplus daytime production was technically feasible, but at a far greater cost per unit of stored energy than gas. Therefore sufficient generating plant had to be installed to meet the peak when it occurred.

In the 1880s generating plant used exclusively for lighting would simply close down during the day. This left very capital-intensive equipment underutilised, and so spurred electricity suppliers to encourage, through promotion and the price structure, the development and use of appliances which would create daytime sales. In Sydney such practices persisted into the 1960s, well past the time when the appliances promoted were themselves the main cause of the system peaks.

Although electricity storage between the generator and the conversion device remains technologically impossible, it is feasible to store energy in other parts of the electricity system, between the mining of coal and the final consumption of the energy service. Each storage device represents an investment of capital, the cost of which must be weighed against its advantages in reduced operating costs or enhanced security of supply. The historical trend has been for elements of the electricity system both upstream and downstream of generation to become more continuous. The stockpiling of coal at the mine mouth and the power station has been reduced or even eliminated through the organisation of work shifts and continuous conveyors. Electricity demand has also been made more continuous. At times when the demand for energy services is low, off peak water heaters create a demand for electricity and store the energy for later use.

As a consequence, the modern city's demand for electricity reflects only partially the daily rhythm of urban life, and remains high even when the level of urban activity is at its lowest. An hourly analysis of 1982 loadings on Sydney substations serving a representative mix of residential and industrial areas reveals that on a cold day in August the peak demand, 42% above the mean 24 hour rate, occurred at 6.30 pm, when people returned home, switched on lights and heaters, and prepared the evening meal. At 4.30 am, the time of minimum demand, there were still enough space heaters, off peak water heaters, refrigerators, street lights and pumps operating to create a demand 54% of the mean 24 hour rate.[22] There is no time of the day or the year when a failure of any link in the chain of electricity supply will be without cost to the Sydney energy system.

The combination of complexity and continuity makes modern electricity systems very sensitive to variations in state. Understandably, this has led system designers and managers to be preoccupied with the technically demanding task of managing virtually instantaneous changes. Even longer term decisions such as the construction of new power stations are largely determined by forecasts of the load curve: projections of how the total system will vary on a minute by minute basis ten years in the future.

The daily and annual load curves are superimposed over much longer cycles of change in the energy system. Some of these are illustrated on a logarithmic time scale in Table 1.8, extending ten millenia into the past, or roughly the span of recorded history. The archaeological evidence suggests that the period between 9000 BC and 4000 BC saw the development of village settlement and agriculture along the rivers of the middle east (Mumford 1961,27). This changed the fundamental spatial relationship of humans to the bio- and geo-energy systems. Since each permanent shelter had its own hearth, it also stimulated further development of what was perhaps the central techno-energy innovation in human history, the control of fire (ibid).

The first records of two further seminal techno-energy developments, the domesticated horse and the wheeled vehicle, are about six millenia old (Ubbelohde 1963,20). By 1000 BC there were in the Mediterranean region a number of cities reliant on a characteristicly urban concentration of bio-energy flows (Mumford 1961,273-81). At about the same time water mills, possibly invented simultaneously in China and northern Europe, began to appear (White 1962,80). Over the following millenium water power became the central focus of techno-energy development in mediaeval Europe. The survey of England carried out by the compilers of the Domesday Book at the end of the 11th century recorded a suprisingly high ratio of one water mill to every 250 people (Gimpel 1979,24). Then, about three centuries ago, the utilisation of fossil fuels began to transform the world techno-energy system to its modern state (Ubbelohde 1963,15).

The electrification of the industrialised techno-energy system commenced about a century ago. It is the latest phase in the evolution of the system, and unlikely to be the last. However, few histories of electrical technology place it in this context. Most search for its origins in the state of scientific knowledge about electricity and magnetism in nature (see for example Dunsheath 1962,21-34). The present model of centrally generated electricity is too often treated as a novel, self-contained scientific and technological phenomenon. In reality its development shows the mark of the spatial, temporal, economic and social forces which have always acted, and continue to act, on the energy system.

### The Economic Model

The dominant contemporary model for the relationship between electricity supply and demand is the economic. The major elements in the economic model are the price of electricity and alternative fuels, and the size, income and level of economic activity of aggregate consumer groups. Reviewing trends in Australian electricity demand in the two decades to 1975, McColl concludes:

> "Growth in population and increases in real income per head were the principal determinants of the growth in domestic use of electrical energy and the fall in its relative price also appears to have contributed strongly to higher levels of consumption. There was an even faster rate of growth of industrial use, which was attributable not only to the generally high rate of growth of industrial production but also to an even faster growth of a number of industries which are heavy users of energy. Technological change in industry, which appears to have been frequently biased toward greater use of electricity per unit of output, has also contributed" (McColl 1976,148).

The historical relationships between elements in the economic model of a specific energy system may be determined empirically by econometric techniques, if sufficient data are available. These relationships are then assumed to hold constant in the future, and forecasts of all the elements found to be historically correlated will yield a value for the related variable of interest:

> "Assumptions are made about the major parameters which drive the model - future energy prices, economic growth rates for the various sub-sectors and demographic parameters (population, household numbers)" (EnANSW 1985a,3).

The economic model is the basis used by the EnANSW and the ECNSW for forecasting the general demand for electricity and other fuels - and so, indirectly, the need for further investment in electricity supply. It has not been spectacularly successful. During 1982, a few years after it had committed itself to the construction of a further 3300 MW to meet an expectation of 6% per annum growth in energy demand up to 1990, the ECNSW halved its official projections to 3% (ECNSW 1983,12). The steps already taken nevertheless resulted in record excess supply capacity in the NSW electricity system.

Even if competently applied, the economic model of the electricity system has inherent limitations. Firstly, it is an imperfect model of the price of energy services. It accounts only for the price of energy and not the costs associated with purchasing, installing or maintaining the energy conversion equipment. This assumption is more or less acceptable in the industrial sector, where energy use per item of conversion equipment is typically high, but less so in the commercial and residential sectors, where the energy cost may be a quite small proportion of the cost of service. It may be as high as 85% over the lifetime of a simple thermal device such as a water heater, and as low as 15% for a complex information device such as a small colour television set.[23] Table 1.9 summarizes average Sydney expenditure on households techno-energy services (ie appliances and their energy requirements), transportation services and bio-energy (ie food). It shows that direct energy costs made up only 35% of Sydney household energy service expenditure in 1974/5, rising to 43% in 1984.

The failure to accurately model the demand for energy services also limits the ability of econometric techniques to account for longer term substitution in the technology/fuel alternatives for supplying those services. For example the demand for space heating could be satisfied not only by conventional heaters but by gas or electric heat pumps, waste heat from other appliances, changes in building design (better insulation and solar orientation) or different standards of occupant dress.

A second limitation of the economic model is the strong assumption that consumer decisions are predominantly based on cost. This may hold for the industrial and commercial sectors, but is highly questionable for the residential. The Sydney householder's choice of fuel and equipment to provide the desired energy services depends on many factors. With the exception of electricity, not all energy forms are readily available to all dwellings. Where alternative fuels are available both cost and non-cost factors are influential. A 1987 study by the EnANSW of the relative costs of using gas or electric energy to supply thermal energy services to Sydney households concluded that apart from cost factors:

> "There are also non-cost, subjective factors which cannot be readily quantified but which are influential in fuel choice. These include perceived quality of service, habit, familiarity, image and psychological associations" (EnANSW 1987b,2).

These complicating factors may lead to persistence with a familiar fuel in the face of cost reasons for change, or change in response to such stimuli as advertising. Sydney gas and electricity suppliers have advertised continually and actively since the 1920s, and most of the material directed at householders has emphasised non-cost considerations such as image (see A.Spearritt 1983).

Perhaps the most serious deficiency of the economic model is the inherent assumption that the relationships between its elements are largely invariable. Statistically valid econometric relationships can only be established over time periods in which relationships are relatively stable, or can be made to appear so by mathematical techniques. The EnANSW selected the 19 year period immediately preceeding 1984, discarding two deviant years, for modelling and then forecasting residential energy demand for the 20 years to 2005 (EnANSW 1985a,28). This built into the forcasts the assumption that relationships established during a period of rising household appliance penetration, and declining real electricity price, would continue indefinitely into the future, despite evidence that the trends had slowed or even reversed.

The imperfect characterisation of energy services, the exclusion of non-cost factors, and the brevity of its time horizons limit the usefulness of the conventional economic model of the electricity system for longer term analysis and forecasting of consumption trends, particularly in the residential sector. This has been recognised by utilities in the USA. A survey of forecasting techniques used by the largest US electricity utilities between 1972 and 1984 found that the trend analysis generally used in the early 1970s was succeeded by econometric modelling in late 1970s, which was itself beginning to be replaced by end-use models in the mid 1980s (Huss 1985,34). This succession of techniques was most pronounced in the residential sector.[24]

The further development of end use analysis is hampered by the lack of a theoretical basis explaining the nature and penetration of appliance types, or distinguishing the demand for electricity from the demand for energy services, most of which can be and in the past have been supplied by a wide range of alternative fuel and equipment combinations. The relevance of this to the management of the NSW energy system has been acknowledged by Bartels (1988), the author of the most detailed econometric study of NSW residential energy use so far published:

> "Continuing efforts are required to improve the data base for end-use modelling. Particular attention needs to be given to the dynamics of the appliance stock and fuel changeovers" (Bartels 1988,iv).

It is precisely these dynamics that an end use model of longer term change in the demand for energy services, as distinct from fuels, helps to clarify.

TABLE 1.8
INDICATIVE TIME SCALE OF CHANGE IN THE TECHNO-ENERGY SYSTEM

| LOGARITHMIC TIME SCALE (Years) | CORRESPONDING TIME INTERVAL (Approx) | TYPICAL CHANGES IN STATE OF TECHNO-ENERGY SYSTEM |
|---|---|---|
| 0.0001 | one hour | - duration of cooker, washer, dishwasher appliance cycles |
| 0.0003 | three hours | - duration of evening peak load on the electricity system |
| 0.001 | eight hours | - work day; industrial demand plateau |
| 0.003 | one day | - diurnal load cycle |
| 0.01 | half week | - work week/weekend load cycle; storage capacity of long gas pipeline |
| 0.03 | ten days | - capacity of buffer storage of petroleum transport fuels |
| 0.1 | one month | - billing cycle for large energy consumers |
| 0.3 | three months | - a season; climatic cycles in space conditioning loads |
| 1 | one year | - annual load cycle; organisational budgetary cycle |
| 3 | | - limit of reliable accuracy in demand forecasts; parliamentary or council term |
| 10 | decade | - apliance lifetime; lead time for development of new power station |
| 30 | | - generator lifetime; interval since start of oil dependendence and household electrification |
| 100 | century | - electrification of energy system; development of rail transport |
| 300 | | - industrialisation; age of new world cities; exploitation of coal |
| 1000 | millenium | - development of European agriculture; exploitation of wind and water power |
| 3000 | | - ancient urbanisation; exploitation of slave power |
| 10000 | | - span of recorded history; settlements; wheeled vehicles; domestication of the horse. |

TABLE 1.9
HOUSEHOLD EXPENDITURE ON BIO- AND TECHNO-ENERGY SERVICES
SYDNEY
1974/5 AND 1984

| | 1974/5 | | 1984 | |
|---|---|---|---|---|
| | $/week | % of en. service(a) | $/week | % of en service(a) |
| Electricity | 2.44 | | 8.29 | |
| Gas | 0.72 | | 1.03 | |
| Other Fuels | 0.17 | | 0.30 | |
| TOTAL FUEL & POWER | 3.33 | 35.4 | 9.62 | 42.5 |
| APPLIANCES (Purchase & repair) | 3.34 | 35.5 | 6.43 | 28.4 |
| Television | 2.52 | | 1.55 | |
| Radio, etc | | | 1.10 | |
| VCR & tapes, etc | | | | |
| TV,VCR hire | 0.21 | | 0.21 | |
| Home computer | | | 0.70 | |
| Other Audiovisual | | | 1.06 | |
| ELECTRONICS | 2.73 | 29.0 | 6.56 | 29.0 |
| HH ENERGY SERVICES | 9.40 | 5.8(b) | 22.61 | 5.7(b) |
| ELECTRONIC COMMUNICATIONS (Telephone) | 1.88 | 1.1 | 6.11 | 1.5 |
| BIO-ENERGY (Food and Drink) | 33.76 | 21.0 | 73.14 | 18.4 |
| TRANSPORT ENERGY SERVICES | 25.24 | 15.7 | 57.01 | 14.3 |
| ALL ENERGY SERVICES | 70.28 | 43.7 | | 40.0 |
| TOTAL EXPENDITURE | 160.68 | | 396.37 | |

(Sources: ABS 1975,1976,1986a,1986b)
a. Percentage of total cost of household energy services.
b. Percentage of total expenditure.

## 1.3 THE MISSING ELEMENTS

Current approaches to electrification are deficient in two important respects. In the first instance they concentrate predominantly, if not exclusively, on the development of the technology and organisation of supply. The dynamics of the actual demand for energy services which creates the market for electricity supply has been largely neglected. The second common weakness is in the treatment of the political framework of electrification: Hughes' (1983) analysis of the effect of the political environment on the initial development of electricity utilities up to the 1930s is a notable exception. Histories of particular electricity utilities implicitly acknowledge the importance of their relationship with government: Hannah (1982) with respect to the postwar restructure of the British electricity system, Edwards (1969) the State Energy Commission of Victoria, Thompson (1981) the Tasmanian Hydro-Electric Commission and Anderson (1955) the Sydney County Council. These studies support the conclusion that the political framework is as essential as resource geography and technological history in analysing the electrification of any particular energy system.

### A Typology of End Use

While elements of the energy supply system can readily be grouped by fuel type, categorisation of energy demand is more problematic. A typology of end use suitable for tracking longer term changes in the urban energy system is presented in Table 1.10. Four 'levels of analysis, are proposed. The first level disaggregates energy demand by user groups, or 'sectors'. This is comparatively straightforward because of the care with which the energy suppliers measure the quantity of energy they sell to consumers. Gas and electricity meters are installed at every point of sale: typically dwellings, non-residential buildings and industrial sites. Urban utilities throughout the world have therefore adopted the convention of defining consumers as 'residential', 'commercial' or 'industrial', largely for the purposes of price differentiation.[25] Suppliers of non-reticulated fuels such as oil have generally adopted the same user group categorisation for non-transport sales.

The second level of analysis in Table 1.10 (Level 2) classifies energy equipment as thermal, power or electronic according to the predominant technical characteristic of its design.[26] All gas, oil and solid fuel appliances fall into the category of thermal devices, converting a part of the chemical energy of the fuel into heat. They are distinguished mainly by the target of heat transfer: hotplates transfer heat to food, space heaters to air and water heaters to water. The technology of electricity is incomparably more diverse and versatile, and electrical appliances appear in all categories. Electricity can produce heat by means of electrical resistance. This is the technical basis of electric thermal devices such as ovens, irons, kettles and radiators. Vacuum cleaners and refrigerators convert electrical energy to rotational energy to drive fans or pump refrigerant. Electronic devices such as microwave ovens and radios rely on the electromagnetic nature of the energy form to generate or intercept electromagnetic radiation of other frequencies.

The third level of classification distinguishes between the technical characteristics of a device and the actual energy service it provides. For example a refrigerator uses electricity primarily to power a motor driving a refrigerant pump, and so falls into the category of powered devices at Level 2, but the ultimate aim of the process is to maintain a low temperature for the storage of food. It is a powered device supplying the Level 3 energy service of refrigeration. A food mixer, also a motorised device, supplies the Level 3 energy service of power: the augmentation of human effort in a task which could otherwise be carried out by hand.

Most modern energy equipment is adapted very specifically to a single form of energy: a powered electric device would not operate on a supply of gas. On the other hand it is apparent that many fuel and equipment combinations can deliver essentially similar Level 3 energy services. Low and medium grade heat in particular may readily be provided by any of the energy forms present in the Sydney energy system. Therefore Level 3 analysis of demand reveals the potential for longer term substitution of energy forms within an energy system.

While the commercial sector is far more diverse in function and in built form than the residential sector, there is much in common in the classification of energy equipment and energy service. Many community services such as health care, education and commercial food preparation represent the historical commercialisation and institutionalisation of household functions, and so generate similar demands for energy services. Because commercial buildings usually contain high concentrations of people rather than machines, energy is used for the same physiologically related purposes as in dwellings.

Many of the significant differences between commercial and residential energy demand result from differences in the buildings in which the activities are located. The volume, height and location of many commercial buildings make it difficult for them to be heated, cooled and lit by solar radiation and airflow - ie, directly from the techno-energy system - than is the case with smaller buildings. Large structures also create demand for the additional energy service of interior personal transport, typically by lift and escalator. The Level 3 energy services of low grade heat (associated with space conditioning), power, lighting and information account for a far greater share of office than residential energy use, and medium grade heat (associated with cooking) for less.[27]

Industrial energy use equipment is the most diverse of all the consumption sectors. Although most factory sites contain some offices and employee facilities with a recognisably "commercial" demand for energy services, the manufacturing processes themselves are of course the most energy-intensive elements of industrial energy demand. Industrial energy services encompass the same broad categories as the other sectors, though varying more widely in magnitude and precision: an electric motor in a bakery may have a thousand times the power of a domestic mixer, and be required to operate across a wider range of loadings. In addition, the refining and chemical transformation of materials create demands for energy services not found in the other sectors: for high grade heat (eg in smelting), electrolytic energy (eg aluminium refining) and feedstock energy (eg the manufacture of fertilisers from natural gas).

The federal Bureau of Resource Economics (BRE 1987) estimates of energy consumption by the major types of industrial equipment in NSW in 1984/5 are summarised in Table 1.11. Some qualitative indication of the energy service supplied by each class of equipment is also given. The data do not allow disaggregation to the same level as for the residential sector, but it is apparent that high grade heat is the major industrial energy service, followed by the other heat grades, chemical energy and power.[28]

The types of equipment supplying Sydney's transportation energy services is summarised at Level 2 in Table 1.10. Powered transportation provides the city with four basic energy services: personal and freight movements wholly within the SSD, and movements with origin or destination outside the SSD. The former serve Sydney's internal spatial structure and the latter connect the city to the outside.[27]

In 1986, residential users accounted for about 14% of the energy delivered to the SSD, commerce 7%, industry 34% and transport 45%, as shown in Table 1.1. However, the residential sector consumed more of the electricity delivered to the SSD than any other sector (43%) and was itself the most highly electrified (over 75% of residential demand was electricity). There is a strong relationship between Sydney household energy service demand and electricity, and further analysis of household energy demand will form an ideal background to understanding the process of electrification.

## Constant Factors in Long Term Change

NSW residential energy demand for 1986 is analysed in Table 1.12 according to the end use typology presented in Table 1.10. Thermal devices (Level 2) consumed over 70% of delivered residential energy: 60% of electricity, and 100% of gas and other fuels. Further analysis to Level 3 indicates, among other things, that well over half the remaining electricity demand was for the energy service of refrigeration. Yet these patterns of demand were shifting and contingent. To identify the more enduring characteristics of household energy service demand, it is necesary to go to a still further level of analysis, and to adopt a functional typology more suited to tracking long term change. There is no generally accepted convention on such a typology, and researchers on residential energy use tend to adopt ad hoc categories to suit their purposes and data.[30]

As the demand by residential consumers for fuels and equipment is derived from their demand for energy services, so the demand for those services is derived in turn from more general physiological and social needs, the satisfaction of which is the ultimate purpose of the techno-energy system. Cipolla begins his chapter on energy in *The Economic History of World Population* with:

> "Man has 'wants' which he likes to regard as 'needs'. He has basic physiological needs for food and drink. He has other elementary wants for clothing and heating. Finally he has, as it were 'high standard' wants, like reading, listening to music, travelling and amusing himself. Human wants have no upper limit, but they have a lower limit - the minimum food necessary to maintain life" (Cipolla 1976,35).[31]

Level 4 on Table 1.10 links personal physiological and social needs to the techno-energy demands associated with food, personal care, environmental control and communications/information. A household is, by definition, a group of individuals related by family or other ties sharing a dwelling. The pattern of Level 4 end use therefore reflects the stability of basic human needs, as expressed in the organisation of household tasks and the physical structure and equipment of the dwelling.

The basic functional organisation of the European predecessors of modern Australian dwellings has shown remarkable stability across class and geographical boundaries over the past millenium. In the mediaeval European urban household (described in Mumford 1961,324-331), the upper class English country house of the eighteenth century (Girouard,1980) and both urban and rural British dwellings of the past three centuries (Davidson 1982) the organisation of tasks around food preparation, personal care and hygiene and environmental control are clearly discernible.[32] These functions, and their associated techno-energy demands, were just as clearly defined in the typical Sydney household of 1986.

The translation of Level 4 needs into Level 3 demand for residential energy services depends, of course, on a range of factors including culture, income, household technology and the organisation of household tasks. Davidson writes in her history of housework in the British Isles from 1650 to 1950:

"Apart from preparing food, housework does not consist of a fixed body of activities common to all people at all times; its scope varies from one culture and time to another" (Davidson 1982,1).

Nevertheless Davidson is able to classify housework into 6 major activities: fetching water, cooking, heating, lighting, cleaning and laundry. The spread of piped water, "the single most important change in housework during the three centuries" (ibid,3), eliminated the first. The others remained, each with their characteristic demand for energy services.

The human need for food creates the tasks of acquiring, storing, preparing, and cooking food and then cleaning up and waste disposal. The organic structure of food itself requires medium grade (100-400 C) heat to achieve the chemical and physical transformations generally called 'cooking'. The methods for achieving this are relatively few and widespread: the technological lineage of the modern cooking range can be traced unbroken back to the open cooking fire.[33] Preparation and cleaning up have always required labour and low grade (below 100 C) hot water. Over the past century traditional hand tasks such as mixing, grinding and dishwashing have gradually gained some assistance from machines, though these were generally powered by hand until the relatively recent spread of purpose-designed electric appliances.

Refrigeration as a household energy service is relatively recent. Fresh food chilling was introduced into Sydney's wholesale food distribution in the 1870s. In the 1880s it became part of Level 4 food energy service demand in some households, where food was stored cold with the aid of factory-made ice. Level 3 demand for mechanised household refrigeration developed in the first half of the present century. Its early technology was based on the absorption principle, variations of which used a range of thermal energy sources, including kerosene, gas and electric heating elements. The electric motor compressor refrigerator proliferated after 1950, and by 1986 refigerators consumed nearly half of food-related electricity in NSW households.

The energy service requirement for personal care is created by the demand for low grade hot water for bathing, and by the activities of washing, drying and ironing clothes. The quantity and quality of energy services required depends very much on cultural and personal preference in such matters as frequency, temperature and method of bathing and clothes washing. There are also climatic variables such as the ambient temperature from which water must be heated, and the suitability of the weather for outside clothes drying (combined with other factors such as the availability of the appliances and the personal time for clothes washingat home).

Clothes washing and ironing were among the most laborious and energy-intensive of the routine tasks in the nineteenth century British household, even after piped water became common, and were often hired out to washerwomen (Arnold & Burr 1985,149). Laundry mechanisation therefore attracted considerable attention from innovators, who correctly perceived a ready market for products which successfully reduced the drudgery of these tasks. Many of the earliest energy appliances on the Sydney market were related to laundry. The gas copper pre-dated the general gas water heater, and the iron was the first electric appliance to follow electric lighting into Sydney homes.

Environmental control embraces three of the traditional household tasks defined by Davidson (1982): lighting, heating and house cleaning. The relatively small proportion of modern Sydney household energy demand made up by lighting - less than 4% - belies its importance in the history of the energy system. Sydney's municipal administrators always regarded adequate lighting as vital to the security and control of the city's public spaces. The demand for public and commercial lighting justified the establishment of first the gas and then the electricity systems, and constituted the main economic foundation from which they spread to other sectors. The demand for a higher quality of private lighting spearheaded the entry of gas, and in due course electricity, into the household.

The residential demand for space heating and cooling is influenced by climate, building and equipment design, occupant expectations of internal temperatures and their use of space within the dwelling, income and the actual cost of energy. The other major component of environmental control, house cleaning, has been the most culturally variable of the traditional tasks in the British and Australian household. Around the 1820s "the status of cleaning was transformed; it ceased to be a peripheral aspect of housework and became one of central importance" (Davidson 1982,128). Unlike any other household task it was "widely considered to be a moral duty" (ibid 117). The effectiveness of house cleaning was greatly increased by the invention of the vacuum cleaner in 1901 (ibid 127), but many environmental control tasks (window washing, tidying up etc) have resisted effective mechanisation and remain as labour intensive as ever.

The remaining group of Level 4 energy services purchased by households specifically serves higher level needs for communication, information, social interaction and entertainment. The equipment providing these services is typically of the electronic type (eg radios or VCRs) and uses little energy in comparison with its purchase price; the energy cost is a small proportion of the cost of service.[34]

As indicated in Table 1.12, nearly 40% of the energy consumed in NSW households in 1986 was used for food-related purposes, nearly 30% each for personal care and environmental control and less than 2% for information and communications. Electricity supplied all or most of the energy for each purpose, except environmental control. The impact of climate on household energy demand is illustrated by comparison with Victoria, the only other state with sufficiently detailed data to permit Level 4 energy demand analysis. Table 1.13 shows that food and information related residential energy use per capita was remarkaby similar in the two states, suggesting that climate-independent household energy demand is largely consistent across Australian regions. On the other hand Victorians used 66% more personal care energy, and 250% more environmental control energy (most of the latter for space heating). This may be explained partly by climate and partly by fuel mix: Victorian households are far less electrified than in NSW, so more energy must be delivered to supply the same useful energy at the point of use.[35]

Residential energy demand also shows considerable consistency across income groups. The economic model of energy demand implicitly assumes that as long as household income rises and the price of energy falls, household energy demand will continue to increase (eg McColl 1976,15-22). This is not necessarily so. Cross-sectional analysis by Bartels of 1984 NSW household energy use found that electricity and gas consumption both rose rapidly with income for lower income groups, but for households with incomes above $ 10,000 consumption increased "at a less dramatic, though steady rate" (Bartels 1988, ii). This suggests that as households become more wealthy, and once they acquire the basic appliances which satisfy their demand for the traditional and most energy-intensive services, the additional services they tend to consume at home become less energy-intensive. Longitudinal data on Sydney household expenditure further reinforce this view. Table 1.9 indicates that the "electronics" proportion of expenditure on energy equipment increased from 45% to 50% in the decade to 1984.

It is apparent that the demand for energy services, in the household at least, is largely determined by physiological and historical factors beyond the scope of the usual economic and climatic models. It is difficult to account for long term changes in the demand for energy without systematically analysing trends in the underlying demand for energy.

### Ministers and Managers: The Political Dimension

Political and management structures are essential features of any techno-energy system. Governments set the legislative matrix in which electricity and other energy suppliers operate, whether or not they take an active part in the management of the supply organisations. Patterns of electrification have been influenced by the prevailing political climate from the very beginning:

> "In Chicago, technology dominated politics; in London, the reverse was true; and in pre-World War I Berlin there was coordination of political and technological power" (Hughes 1983,462).

Sydney's electrification was much influenced by British legislative prototypes and notions of ownership. The NSW electricity supply system was predominantly publicly owned after 1904, and exclusively so after 1950, when the last significant private supplier, in Sydney's inner west, was nationalised. The structure of the system was unusually complex in comparison with other Australian states, involving several organisations and layers of government, often with competing interests.

The organisation of the distinct functions of energy policy development, electricity co-ordination, generation/bulk transmission, and distribution in each state in 1986 is summarised in Table 1.14. The domination of the Tasmanian energy system by hydro-electricity was clearly reflected in the simplicity of the administrative structure. There was an equally compact structure in Western Australia, where after 1975 a single State Energy Commission was responsible for both the electricity and gas systems, as well as for general energy policy advice to the government. In Victoria and SA separate semi-government authorities were responsible for unified electricity systems and for gas reticulation. NSW and Queensland had a two-tier electricity organisation with a single generating body and a number of distributors. In Queensland these were co-ordinated by the generating body, and in NSW by a separate organisation, the Energy Authority. NSW and Queensland were the only states in which gas reticulation was privately owned, though still subject to a measure of government control.

The Queensland Electricity Commission and seven area boards were all regulated by the Electricity Act 1976-84, and all responsible to the Minister for Mines and Energy. In NSW, however, there were 26 county councils distributing electricity. All but one were established under the Local Government Act 1919, and responsible to the Ministers for Local Government and Energy separately for various aspects of their operations. The Sydney County Council, the ECNSW and the EnANSW were each established under separate legislation, and stood in different relationship to the Minister for Energy.[36]

In NSW and Sydney both the electricity supply industry and government control of it were fragmented and diffuse. These same structural characteristics gave the management of Sydney's water supply and transport systems a history of conflict and inefficiency (see Wilenski 1986), and in the 1980s it became evident that they had led to ambiguities in the definition of responsibility, conflict in objectives, tension between parties and, ultimately, inefficiencies in the management of electricity supply. In response to pressure from the ECNSW to approve new power station sites, the Minister for Energy P.F.Cox established the first ever public inquiry into NSW electricity generation planning in May 1985. The report was highly critical of the ECNSW. It concluded, among other things, that the ECNSW's forecasting techniques were inadequate, that it was not using its existing generating resources effectively, and that its coal sourcing was inefficient and costly (McDonell 1986 I,10-19). These findings substantially undermined the ECNSW's justification for the huge investment programme to which it was contractually committed. The central issue of electricity pricing also led to conflict. In October 1986 the county councils publicly called on the minister to reject any increase in the bulk supply tariff (BST) charged to them by the ECNSW on the grounds that it would interfere with their marketing objectives (SMH 27.10.86). The minister then held an independent inquiry into the BST, also the first of its kind (EnANSW 1987,12).

These developments gave cause to question the entire basis for the planning and management of the state's largest public enterprise. If the government, nominally reponsible for the system, was only now belatedly asserting its authority over it, whose policies and objectives had prevailed in the past, what had those policies been, and what were their consequences? Issues of organisational history, policy and conflict are important to understanding the Sydney energy system in 1986.

The protection of management autonomy against government "interference" appears to be a widespread feature of publicly owned electricity utilities. The charters of these organisations usually vest control in elected representatives, but in practice technical managers have often been able to exercise a large degree of autonomy in the pursuit of their own organisational policies. In his account of the postwar nationalisation of British electricity industry, Hannah notes that

> "Much of the debate [among senior managers] on the public corporation had centred on the need to leave decisions to a professional, technocratic elite ... There was ... a long tradition in the industry of distrust of political intervention in its affairs from politicians of all colours" (Hannah 1982,4).

Edwards speculates, in his history of the SECV, on the reasons for the general success of management in resisting intervention:

> "For two reasons, public electricity corporations throughout the world seem to enjoy more freedom from interference than some similar bodies: first, because electricity is an esoteric matter in which the layman admits himself lost and, second, because they usually pay their way" (Edwards 1969, 24).

The managers of technological enterprises can of course choose to make their activities more "esoteric" to discourage scrutiny of their activities by government or the public. Croxon (1982) concludes that the ECNSW management used this very device "to become a technocracy, with ministerial control of the organisation existing in name only" (p19).

While management autonomy in the NSW electricity supply system may not extend as far as in Tasmania, where the power of the monolithic Hydro-Electric Commission is said to exceed the power of the state goverment itself (Thompson 1981,13), Saddler comments that the NSW supply industry shares with its Tasmanian and Victorian counterparts "secretive, devious and dogmatic" management with a "hierarchical and authoritarian" structure (Saddler 1980,115). McColl (1976,150) also notes and regrets the secretiveness of Australia's public electricity authorities.

These observations suggest that the policies and motivations of NSW politicians and of the electricity supply organisations under their nominal control must be viewed as separate. Pricing, security of supply and grid extension tended to be the main focus of NSW state government electricity policy. The relative policy emphasis and the distribution of the benefits of electrification have of course varied according to which party is in power. All NSW governments have exhibited a tendency which Clarke (1986) has identified as common to Australian state governments: to exploit the "potential for cross-subsidisation inherent in uniform pricing policies" in order to pursue their distributional and locational objectives, and to "disguise the support given to beneficiaries of current pricing policies" and its cost to economic efficiency (p139). This is consistent with the general reluctance in the industry, noted by McColl (1976,149) to examine variations in the cost of supply to different consumer groups, let alone formulate prices to reflect it.

The over-riding policies of electricity supply organisations seem to have been autonomy and growth. Sometimes this objectives were consistent with those of government: the desire of the Sydney Municipal Council to expand its area of supply in the 1920s, and of the ECNSW to expand the grid to rural households in the 1950s, were complementary with the wishes of the governments of the day. However, the growth objective still very evident in the 1970s:

> "One aspect of the situation which is particularly worrying is the apparent desire of electricity authorities to grow at the fastest possible rate ... Whether this results from the tendency for executives of all large organisations to attempt to keep their sales growing as fast as possible or whether it is related to the genuine belief that such policies lower average costs, it is clearly time that the situation was carefully investigated" (ibid,150).

The dynamics of government and organisational management provide a fundamental political dimension to the electrification of the Sydney energy system. They establish a context for the interaction of the spatial, temporal, economic and end use elements in the process. Writing on the politics and economics of energy in Australia, Saddler remarks that

> "...by and large energy use patterns are the outcome of social processes; they are the consequence of the way our society operates. In other words, they are the result of decisions by governments and large corporations, both public and private, for all of which growth is usually of central importance. The energy industries are certainly no exception to this rule" (Saddler 1980,77).

TABLE 1.10
CLASSIFICATION OF END USES
IN THE URBAN ENERGY SYSTEM

| LEVEL 1: USER GROUP & location | LEVEL 2: EQUIPMENT TYPE(a) | LEVEL 3: ENERGY SERVICE(a) | LEVEL 4: PURPOSE(a) |
|---|---|---|---|
| RESIDENTIAL: in dwellings | POWERED eg Refrigerator, Air conditioner, mixer<br>THERMAL eg Hotplate, Oven, Heater<br>ELECTRONIC eg Light, Microwave oven, TV | POWER<br>REFRIGERATION<br>LOW GRADE HEAT<br>MEDIUM GRADE HEAT<br>LIGHT<br>INFORMATION/ COMMUNICATION | FOOD: bio-energy<br>PERSONAL CARE: hygiene, clothing<br>ENVIRONMENTAL CONTROL<br>INFORMATION/ ENTERTAINMENT |
| COMMERCIAL: in non-residential buildings | Larger, more robust version of Residential types, plus:<br>POWERED eg Lifts, Escalators<br>ELECTRONIC eg Computers, Medical & Office equpt | As for Residential, plus<br>PERSONAL TRANSPORT large buildings | As for Residential, but related to consumption of services outside the dwelling, or to later consumpt-ion at home |
| INDUSTRIAL: in industrial buildings or at sites of production | As for Residential and Commercial, plus:<br>POWERED eg Conveyors, Crushers, Mills, Cranes<br>THERMAL eg Kilns, Ovens, Dryers, Boilers<br>ELECTRONIC eg Induction Dryers, Welders, Platers | As for Residential & Commercial, plus<br>HIGH GRADE HEAT (b)<br>ELECTROLYSIS<br>FEEDSTOCK (c) | Wide range of material-centred processes, includ-ing the production of derived fuels & energy using equipment |
| TRANSPORT: in public spaces | VEHICLES eg cars, buses, trucks, motorcycles<br>TRAINS<br>WATERCRAFT eg ferries | PERSONAL TRANSPORT Within and beyond metropolitan area<br>GOODS TRANSPORT Within and beyond metropolitan area | JOURNEY TO WORK & in course of work<br>SHOPPING<br>EDUCATION<br>PERSONAL BUSINESS<br>MOVEMENT OF RAW MATERIALS<br>DISTRIBUTION OF PROCESSED GOODS<br>WASTE COLLECTION(d) |
| URBAN SERVICES: in public spaces | POWERED eg water pumps<br>ELECTRONIC eg Street & Traffic Lights | As for Residential & Commercial, for the whole city | PUBLIC SAFETY & HYGIENE |

a. See Notes to Table 1.12.
b. Above 400 C.
c. A reaction with the main purpose of effecting a chemical transformation, but which may be accompanied by the release or absorption of heat.
d. Classification of trip purpose adopted by Sydney Area Transportation Study; it may be possible to match trip purposes to personal consumption, and hence to residential and commercial sector energy purpose.

TABLE 1.11
INDUSTRIAL ENERGY DEMAND BY EQUIPMENT TYPE AND ENERGY SERVICE
NSW
1984/5

| EQUIPMENT TYPE | ENERGY CONSUMPTION (PJ) | ENERGY SERVICE |
|---|---|---|
| INDUSTRIAL | | |
| Boilers | 467.6 (d) | High & medium grade heat |
| Dryers | 2.4 | Medium and low grade heat |
| Cooking equipment | 1.8 | Medium grade heat |
| Kilns | 23.2 | High grade heat |
| Metallurgical process equipment (a) | 273.3 | High grade heat, chemical and electrolytic |
| Chemical and refining equipment | 396.8 (e) | High & medium grade heat, chemical |
| Stationary engines | 2.2 | Power |
| General equipment (b) | 42.2 | Power, low grade heat |
| Non-fuel use | 59.2 | Chemical |
| TOTAL | 1268.6 | |
| TOTAL INDUSTRIAL | 627.2 (f) | |
| COMMERCIAL APPLIANCES | 30.5 | |
| DOMESTIC APPLIANCES | 81.5 | |
| MOBILE ENGINES | 319.1 | |
| OTHER (c) | 3.4 | |
| CONVERSION INDUSTRY EQUIPMENT | 34.5 (g) | |
| NSW TOTAL | 1096.2 | |

(Source: derived from BRE 1987, pp 75, 194-8)

a. Including coke oven and electrolytic equipment
b. Principally industrial electric motors and space heaters
c. Principally illumination and communication equipment
d. Estimated 280 PJ of boiler fuel used to raise steam for electricity generation
e. Estimated 360 PJ used to produce petroleom products for use in other equipment, principally mobile engines
f. Energy used in the production of secondary energy forms consumed elsewhere in NSW (ie (d) and (e) above) excluded
g. Mainly pumps, fans, gas reformers etc - boilers included above

## TABLE 1.12
## END USE ANALYSIS OF RESIDENTIAL ENERGY DEMAND
## NSW
## 1986

| ELECTRIC APPLIANCE | % CONS (a) | LEVEL 2: APPLIANCE TYPE Pwr (b) | Therm (c) | Ele (d) | LEVEL 3: ENERGY SERVICE Pwr (e) | Ref (f) | L Ht (g) | M Ht (h) | Lght (i) | Info (j) | LEVEL 4: PURPOSE Food (k) | Care (l) | Env (m) | Info (n) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Freezer | | | | | | | | | | | | | | |
| Refrigerator | | | | | | | | | | | | | | |
| REFRIG(o) | 21.0 | 21.0 | | | | 21.0 | | | | | 21.0 | | | |
| Cooker | 10.4 | | 10.4 | | | | | 10.4 | | | | | | |
| Frypans | 1.0 | | 1.0 | | | | | 1.0 | | | | | | |
| Jugs,etc | 2.0 | | 2.0 | | | | | 2.0 | | | | | | |
| Mixers,etc | 0.7 | 0.7 | | | 0.7 | | | | | | | | | |
| Microwave | 0.3 | | | 0.3 | | | | 0.3 | | | | | | |
| COOKING | 14.4 | | | | | | | | | | 14.4 | | | |
| DISHWASHER | 3.7 | 3.7 (p) | | | 3.7 | | | | | | 3.7 | | | |
| Washer (p) | 3.0 | 3.0 | | | 3.0 | | | | | | | | | |
| Dryer (q) | 3.7 | 0.2 | 3.5 | | | | 3.7 | | | | | | | |
| Iron | 0.4 | | 0.4 | | | | | 0.4 | | | | | | |
| LAUNDRY | 7.1 | | | | | | | | | | | 7.1 | | |
| Peak | 10.2 | | 10.2 | | | | 10.2 | | | | | | | |
| Offpeak | 22.4 | | 22.4 | | | | 22.4 | | | | | | | |
| HOT WATER | 32.6 | | | | | | | | | | 8.1 | 24.4 (r) | | |
| Radiator | 8.8 | | 8.8 | | | | 8.8 | | | | | | | |
| Air cond | 2.7 | 2.7 | | | | 2.0 | 0.7 | | | | | | | |
| Elect bla | 0.1 | | 0.1 | | | | 0.1 | | | | | | | |
| HEAT/COOL | 11.6 | | | | | | | | | | | | 11.6 | |
| LIGHTING | 5.0 | | | 5.0 | | | | | 5.0 | | | | 5.0 | |
| Television | 1.5 | | | 1.5 | | | | | | 1.5 | | | | 1.5 |
| Radio, etc | 0.2 | | | 0.2 | | | | | | 0.2 | | | | 0.2 |
| Pool pump | 2.1 | 2.1 | | | 2.1 | | | | | | | 2.1 | | |
| Exhaust | 0.2 | 0.2 | | | 0.2 | | | | | | | | 0.2 | |
| Misc (s) | 0.6 | 0.5 | | 0.1 | 0.5 | | | | | 0.1 | | 0.1 | | 0.5 |
| OTHER | 4.6 | | | | | | | | | | | | | |
| % ELEC | 100.0 | 34.1 | 58.8 | 7.1 | 10.2 | 23.0 | 45.9 | 14.1 | 5.0 | 1.8 | 47.2 | 33.7 | 16.8 | 2.2 |
| PJ 1986 | 50.4 | 17.1 | 29.6 | 3.5 | 5.1 | 11.5 | 23.1 | 7.1 | 2.5 | 0.9 | 23.8 | 17.0 | 8.4 | 1.1 |
| GJ/CAP | 9.0 | 3.1 | 5.3 | 0.6 | 0.9 | 2.0 | 4.1 | 1.2 | 0.4 | 0.1 | 4.2 | 3.0 | 1.5 | 0.2 |

(Sources: Calculations based on EnANSW 1987b, Bartels 1988, ABS 1987a,1988a)

a. Percentage of delivered energy used by appliance.
b. Main energy consumer is an electric motor (though may have auxiliary heater, light, etc).
c. Main energy consumer is a resistance heater or a burner.
d. Main energy consumer is an electronic or lighting circuit.
e. Assists or extends human physical effort.

TABLE AND NOTES CONTINUE OVER

TABLE 1.12 (CONTINUED)

| GAS APPLIANCE | % OF CONS (a) | LEVEL 2: APPLIANCE TYPE Pwr (b) | Therm (c) | Ele (d) | LEVEL 3: ENERGY SERVICE Pwr (e) | Ref (f) | L Ht (g) | M Ht (h) | Lght (i) | Info (j) | LEVEL 4: PURPOSE Food (k) | Care (l) | Env (m) | Info (n) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| COOKING | 20.7 | | 20.7 | | | | | 20.7 | | | 20.7 | | | |
| HOT WATER | 54.9 | | 54.9 | | | | 54.9 | | | | 13.7 | 41.1 | (r) | |
| HEATING | 24.4 | | 24.4 | | | | 24.4 | | | | | | 24.4 | |
| % GAS | 100.0 | | 100.0 | | | | 79.3 | 20.7 | | | 34.4 | 41.1 | 24.4 | |
| PJ 1986 | 7.4 | | 7.4 | | | | 5.8 | 1.5 | | | 2.5 | 3.0 | 1.8 | |
| GJ/CAP | 1.3 | | 1.3 | | | | 1.0 | 0.2 | | | 0.4 | 0.5 | 0.3 | |
| COOKING | 11.0 | | 11.0 | | | | | 11.0 | | | 11.0 | | | |
| HOT WATER | 10.8 | | 10.8 | | | | 10.8 | | | | 2.7 | 8.1 | (r) | |
| HEATING | 78.2 | | 78.2 | | | | 78.2 | | | | | | 78.2 | |
| % FUEL(t) | 100.0 | | 100.0 | | | | 89.9 | 11.0 | | | 13.7 | 8.1 | 78.2 | |
| PJ 1986 | 14.0 | | 14.0 | | | | 12.4 | 1.5 | | | 1.9 | 1.1 | 10.9 | |
| GJ/CAP | 2.5 | | 2.5 | | | | 2.2 | 0.2 | | | 0.3 | 0.2 | 1.9 | |
| % ALL | 100.0 | 23.9 | 71.0 | 4.9 | 7.1 | 16.1 | 57.7 | 14.1 | 3.5 | 1.2 | 39.3 | 29.5 | 29.5 | 1.5 |
| PJ 1986 | 71.8 | 17.1 | 51.0 | 3.5 | 5.1 | 11.5 | 41.4 | 10.1 | 2.5 | 0.9 | 28.2 | 21.1 | 21.2 | 1.1 |
| GJ/CAP | 12.9 | 3.1 | 9.2 | 0.6 | 0.9 | 2.0 | 7.4 | 1.8 | 0.4 | 0.1 | 5.1 | 3.8 | 3.8 | 0.2 |
| FUEL SHARE % | | | | | | | | | | | | | | |
| ELECT | 70.1 | 100 | 58.0 | 100 | 100 | 100 | 55.7 | 69.8 | 100 | 100 | 84.2 | 80.2 | 39.9 | 100 |
| GAS | 10.3 | | 14.4 | | | | | 14.1 | 15.0 | | 9.0 | 14.3 | 8.5 | |
| OTHER | 19.4 | | 27.4 | | | | | 30.0 | 15.1 | | 6.7 | 5.3 | 51.5 | |

f. Cools compartment or space.
g. Low grade heat: up to 100 C, mainly applied to water or air.
h. Medium grade heat: between 100 C and 400 C, mainly applied to food.
i. Area or task lighting.
j. Communications and Information: sound and image transmission, recording etc.
k. Related to food storage, preparation, cooking, consumption etc.
l. Related to personal care: washing, clothing etc.
m. Related to environmenal control for safety and comfort.
n. Related to personal communication and entertainment.
o. Refrigerator and freezer consumption not disaggregated in data.
p. All water heating energy assigned to central water heater: probably correct for clothes washers, but ignores some self-heating by dishwashers.
q. Rotary type: air heating and clothes agitation both important to function.
r. Hot water use estimated 25% for food (ie cooking, wahing up etc) and 75% for personal care (washing, clothes washing etc).
s. Hair dryers, power tools, personal computers etc.
t. Maily firewood, also oil and solar. Firewood use assigned on assumption that households use equal tonnages annually for water heating and cooking, (where wood used for those purposes) and half as much for space heating.

TABLE 1.13
RESIDENTIAL ENERGY SERVICES AND FUELS
NSW 1986 AND VICTORIA 1982

| | NSW 1986 | | | | | | VIC 1982 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ENERGY SERVICE(a) | % of energy (b) | | | | % ELE (c) | GJ/ CAP | % of energy (b) | | | | % ELE (c) | GJ/ CAP |
| | ELE | GAS | OTH | TOT | | | ELE | GAS | OTH | TOT | | |
| Food | 47 | 34 | 14 | 39 | 84 | 5.1 | 43 | 16 | 17 | 23 | 49 | 6.1 |
| Personal Care | 34 | 41 | 8 | 30 | 80 | 3.8 | 32 | 26 | 14 | 24 | 35 | 6.3 |
| Environmental Control | 17 | 24 | 78 | 30 | 40 | 3.8 | 19 | 59 | 70 | 51 | 10 | 13.4 |
| Information | 2 | - | - | 1 | 100 | 0.2 | 5 | - | - | 1 | 100 | 0.3 |
| Total | 100 | 100 | 100 | 100 | 70 | 12.9 | 100 | 100 | 100 | 100 | 27 | 26.3 |

(Source: derived from Table 1.12 and from SECV 1984a)
a. Level 4 energy service as clasified in Table 1.10
b. Percentage of each of the energy forms delivered to the residential sector which is assigned to the nominated service
c. ie degree of electrification of that service

TABLE 1.14
ORGANISATION OF RETICULATED ENERGY SUPPLY BY STATES
AUSTRALIA
1986

| FUNCTION | NSW | VIC | QLD | SA | WA | TAS |
|---|---|---|---|---|---|---|
| Energy Policy -development | EnANSW | DEPT (f) | DEPT (f) | DEPT (f) | SECWA | HEC |
| Electricity co-ordination | EnANSW | - | QEC | - | - | - |
| Generation and transmission | ECNSW | SECV | QEC | ETSA | SECWA | HEC |
| Electricity distribution | CCs (a) | SECV (b) | ABs (c) | ETSA | SECWA | HEC |
| Gas reticulation | AGL | GFCV | Priv (d) | SAGASCO (e) | SECWA | - |

(Sources: Saddler 1981,111; EnANSW 1986b).
a. 26 local goverment county councils
b. About 18% of electricity is sold by the SECV to 11 Melbourne municipalities and resold under the supervision of the SECV
c. 7 area boards
d. In Brisbane: Allgas Energy and Queensland Gas Corporation
e. State government assumed majority shareholding in 1987
f. Department of the state government responsible for Energy

See Table of Abbreviations for full names of organisations.

## 1.4 THE SYNTHESIS OF ELEMENTS

Each of the factors described in the previous sections is present in the Sydney energy system and has shaped the course of its electrification. While the general elements of 'government', 'supply' and 'demand' are common to many descriptions of techno-energy systems (and indeed to most classical models of economic activity), the Sydney energy system is distinguished by a unique combination of resource, spatial and political relationships within a local variant of the Australian economic and technological environment. The elements are of course dynamic, and as they change so does the state of the entire system.

The aim of this thesis is to identify and analyse the underlying changes in the Sydney energy system before and during the process of electrification, using as a starting point the elements and relationships described in this chapter. The Sydney energy system is ideal for such an analysis. It conforms to the general pattern of succession in fuels and technological types found in other industrialised cities at equivalent stages of their development, and in fact illustrates the succession more clearly than most. It encompasses within its two hundred year history a microcosm of the energy history of Europe over the past millenium, from wind power to electricity and natural gas.

### History and Growth

The pre-electric period, from 1788 to 1881, covers several distinct phases. The emerging urban energy system of the colony was the technological and spatial antithesis of the pre-existing aboriginal energy system. It concentrated energy flows at the site of the new settlement, whereas in the aboriginal economy each social unit collected energy nomadically from the diffuse bio-energy system. From 1788 to the 1830s the Sydney techno-energy system was dominated by renewable bio- and geo-energy sources: animal, wind and water power, and wood fuel. Coal was known but in limited use until the introduction of gas reticulation in 1841 and the multiplication of steam engines in industry and transport around mid-century. The local urban energy system was as modern as any in the world by 1881.

Commercial electro-technology was introduced in the early 1880s, and went through the stages of familiarisation and adoption common to technological innovations. This period coincided with important changes in the structure of government and politics in NSW. Attempts by private entrepreneurs to control electricity supply were caught up with the political issues of municipal power, public ownership of essential services and the emergence of the parliamentary Labor

Party. By 1904, when the Sydney Municipal Council began to supply electricity, the precedent for local government ownership was well established.

The Sydney electricity system grew steadily in area and consumer numbers from 1904 to 1932. Growth was driven both by changes in the technology of supply and by the demand for electricity, which was restricted at first mainly to street and commercial lighting, tramway traction and industrial power. Increases in the scale and efficiency of generation lowered the cost of electricity, increased its competitiveness against other fuels and stimulated its penetration into residential energy markets. The capital-intensity of electricity supply, which required constant growth to justify the large investments necessary, and the ambitions of the supply organisations, also emerged as powerful agents for expansion during this period.

From the early 1930s to 1950 there was a succession of crises and reorganisations. The strong underlying growth in demand was interrupted briefly by the depression, then stimulated by war time production, and stalled again by supply problems after the war. State governments increasingly influenced the political direction of the system, but until 1945 stopped short of directly intervening in its management. This allowed the original municipal model of control to become entrenched. When governments did intervene it was primarily to promote rural electrification, and in 1950 to superimpose a structure of centrally controlled state-wide generation over the pattern of local government distribution. This dual structure survives up to the present.

After 1950 the Sydney electricity system formed the nucleus of an expanding state grid. The different retail organisations serving the metropolitan area were progressively absorbed into two county councils. As in 1904-1932, this period in the development of the system was characterised by growth and technological change. The price of electricity fell continuously as the scale of generation increased and new power stations were built on the coalfields. Demand also increased with postwar population and economic growth, and as more energy markets became electrified.

This phase concluded in the late 1970s. The upward cost trend for gas, electricity's historic competitor in the thermal energy market, reversed at about the same time as the downward trend in electricity prices. Just as electricity had displaced previous fuels from various niches in the Sydney energy system, a new fuel with a new cost structure - natural gas - began to succeed petroleum and coal in the industrial energy market, and electricity itself in the residential market. There were also underlying changes in the nature of energy demand. The market for major appliances showed signs of saturation as the electrification of traditional household tasks neared completion. The electricity-intensive manufacturing sector of the economy faltered, and electric traction declined in the face of competition from petroleum powered transportation. The efficiency of end use equipment also began to increase in reponse to electricity price increases and to government encouragement.

These factors, combined with major generating plant failures in 1981/2 and the growing resource requirements of the ECNSW focussed the sustained attention of the government and the public on the electricity system for the first time since the 1940s. This revealed weaknesses in the structure and management of electricity supply which had been masked during the previous period of uninterrupted growth. The span of the thesis concludes in mid 1987, when significant changes in legislative structure gave state governments scope for effective control of the system for the first time in its history.

## Energy, Technology and Urbanisation

The pattern of demand for energy services in each period is examined according to the typology described in Table 1.10. Although energy services were supplied by a succession of fuels and energy forms, and electrified at different times and to different degrees, the fundamentals of end use remained remarkably consistent from period to period. While lighting was completely revolutionised by electricity, the electrification of other end uses was more evolutionary. In many respects it was a consummation of pre-electric trends towards the mechanisation of labour and the finer control of energy conversion. The only completely unprecedented devices introduced en masse after the beginning of electrification were electronic devices, notably radio and television, which actually supplied information and entertainment rather than traditional energy services.

Changes in industrial energy demand in each period are examined against the background of general developments in technology such as the increasing control of the scale, spatial and temporal disposition of power. Sydney's early wind and water mills were extremely inflexible in that power was available only at times when the natural energy conditions were favourable, and only at the point of collection. The steam engine increased the spatial and temporal flexibility, but was too large, noisy and dirty for dense urban areas, and its power could only be distributed via cumbersome rope or shaft drive systems. These problems were partially solved between 1880 and 1910 by gas and oil engines and hydraulic power systems, but they were not fully overcome until the introduction, in the 1920s, of cheap and reliable electric motors connected to an equally cheap and reliable supply.

The demand for energy to power wheeled vehicles is a feature of every period, and the characteristics of successive transport energy forms influenced Sydney's spatial development.

The horse was the backbone of the Sydney land transportation system until 1900, and did not disappear from it entirely until the 1930s. Steam powered trains, introduced in the 1850s, were heavy, dirty, noisy, sluggish in their acceleration, and required expensive rights of way. Electricity increased the flexibility of transportation in much the same way as it increased the flexibility of manufacturing. The electric trams introduced in the 1890s were more suited to new routes along suburban streets. and electric traction applied to Sydney's railways in the 1920s enabled them to run under the inner city, increased their carrying capacity and stimulated suburban development along the railway lines. The demand for greater route flexibility was partly responsible for the replacement of electric tramways with petroleum powered buses, and then private automobiles, in the period after 1950. Consequently, transportation was the first element of Sydney energy demand to be substantially de- electrified.

The offices, shops, hotels and warehouses of Sydney's inner business district, and the streets in which they were located, generated a constant and in some periods a pivotal demand for lighting energy. The central district's high densities of energy demand and expenditure formed the spatial and economic core from which first the gas and later and electricity reticulation systems extended throughout Sydney. The commercial sector was a ready market for new energy equipment. Most of the innovations in electric lighting, cooking, ventilation and refrigeration which later found their way into Sydney's homes were first introduced in its shops, offices and hotels.

The review of each period concludes with a quantitative summary of energy use in each sector, in as much detail as the available data permit. This serves three purposes. It illustrates changes in energy intensity of the major urban activities, in terms such as energy per household, electricity per factory worker, or number of journeys made by various transport modes. Secondly, the degree of electrification of each end use sector is indicated by the proportion of its energy supplied by electricity and the number of users connected. Thirdly, the share of NSW electricity production consumed by sector and by geographical area illustrates the contribution of various regions and consumer classes to the development of the total system. Electricity first gained a foothold in the commercial sector in the 1880s. Industry and transportation were the sectors most rapidly electrified between 1900 and the 1930s. While almost all Sydney households were connected to the system by 1947, the actual electrification of residential energy demand (and the de- electrification of transport), were mainly post-war phenomena.

## Politics and the Benefits of Electrification

The structure of government and the tensions within it are important themes in each period of electrification. One recurrent issue was the balance between private and public control of the elements of the energy system. The private ownership of Sydney's gas system and the public ownership of its electricity system in 1986 largely reflected the ideologies prevailing at the times of their establishment. Political and ideological activity was not restricted to state or local governments and to party politics. The policy making and ideological orientation of the supply organisations themselves is also examined. The commercial motivations of private companies such as AGL and the ELPSC were the most clearly defined and consistent. The objectives of public electricity supply organisations were more complex, leading to frequent internal debates as to whether they constituted essential services or profit-making businesses which happened to be owned by the public.

The management of electricity supply systems required a high degree of technical skill and co-ordination. Electrification was one of the most outstanding successes of what may be termed the 'engineering-economic' approach: the optimum use of resources to achieve narrowly defined material objectives. This approach imbued the management and reward structures of Sydney's public electricity bodies, and in the usual absence of strong direction from the elected representatives of the public, formed the value system underlying their policies. At the same time the role of key individuals in setting organisational goals should not be underestimated. Certain engineer managers exercised exceptional influence over their organisations at various times, as did individual ministers or councillors with a strong personal interest in electricity supply.

As the importance of electricity supply to economic activity and material wellbeing increased, interest groups such as farmers, industrialists and urban householders made competing demands for an inexpensive and reliable supply. The relative contribution of various consumers and regions to costs, and the distribution of benefits between them, was constantly controversial. It prompted frequent public debate, and was increasingly determined at the local or state government level by political rather than economic or financial considerations.

In each period new fuels entered the Sydney energy market and old ones disappeared. Each was associated with a characteristic commercial and technological infrastructure. Firewood, for example, represented a very loosely organised industry, and consumers could always gather their own. At the other end of the scale, gas and electricity were supplied by well organised monopolies with high levels of investment, with strong economic motivations to increase their supply areas and scale of production. The relative price movements between electricity and its major competitors over the past 80 years have been tracked, as far as possible, from supplier records. The structuring of prices to promote the electrification of the residential sector is a consistent theme in public electricity supply since the 1930s. It must be remembered that fuel price alone is an incomplete indicator of the cost of an energy service. The purchase and installation of the necessary equipment or appliance is also part of the cost to the consumer, and indications of comparative appliance costs are given where possible. The influence of non-cost factors, such as the association of electricity with images of municipal progress and household modernity, on electrification are also acknowledged.

In many ways the growth of the NSW electricity grid represented the extension of the Sydney energy system, with all its benefits, beyond the city boundaries. The relationships between the Sydney energy system and the rest of the state fall into four phases of near equal length. For the first 50 years of the colony's existence the systems were essentially indistinguishable in fuel mix and technology, though the concentration of population and manufacturing in Sydney led to a more commercial organisation of supply. In 1837 the founders of AGL judged Sydney's demand for lighting to be sufficiently developed to support their enterprise. In the following 50 years many renewable fuels and energy technologies which remained popular outside Sydney declined or disappeared from the urban energy system, because of competition from gas and other fuels more suited to the increasing spatial and energy demand density of the city. The Sydney energy system became qualitatively distinct from the rest of NSW, and characterised by its increasing dependence on coal.

In the 1880s electricity was introduced simultaneously to Sydney, to other centres in NSW and to other states. After a slow start while the issue of political control was resolved, the rate of electrification was far higher in Sydney than elsewhere. Sydney's increasing gas-intensity further emphasised its distinctiveness. After the second world war the rest of the NSW energy system gradually came to resemble Sydney. The spatially concentrated local energy distribution systems using transported coal, typical of the previous period, were replaced by state wide energy grids, distibuting electricity and then, in the 1970s, natural gas.

Not least of the impacts of electricity has been its unifying influence, on energy markets, on regions and on states. Much of the history of Sydney's electrification can be read through the attempts of the political process to come to grips with a mercurial technological force which, however benign, seems somehow to escape collective comprehension and control. Modelling the process of electrification as a synthesis of individual elements, many of them pre-dating electricity, is a step towards demystification, and ultimately, towards more effective social utilisation of the benefits of electri c ity.

# 2. A PREHISTORY OF ELECTRIFICTION: THE SYDNEY ENERGY SYSTEM TO 1881

## 2.1 RENEWABLE ENERGY AND THE DISCOVERY OF COAL

The founders of Sydney in 1788 displaced the Aboriginal inhabitants of the region and established their own food and energy system modelled on the Britain they had left. At first the Sydney energy system relied exclusively on renewable energy sources, and was organised around the immediate need to feed the colony. The development of the colony's coal resources, the importation of steam engines and the agency of private capital allowed rapid modernisation. By 1841, when gas supply commenced, the Sydney energy system was advanced even by British standards.

### The Aboriginal Energy System

One of the fundamental differences between Aboriginal and early colonial societies was the organisation of the of bio-energy supply. The Aboriginals kept no livestock, grew no crops or vegetables, and rarely hoarded food, which was hunted or collected at the rate at which it was eaten (Blainey 1982,27). The Aboriginals spent their lives mainly in small family units. They followed well established nomadic routes over their tribal territories, and gathered food from a dispersed bio-energy system which varied regionally and seasonally. By contrast the colonists immediately established comparatively large concentrations of population which could not survive without food transportation and storage.

Dry plant matter was readily available as fuel in most parts of the continent, and fire was used in many aspects of Aboriginal life. It was, as Blainey observes, "the core of their technology" (ibid,71). The open fire supplied the Aboriginal family group with energy services still recognisable in the modern household - cooking, light, warmth and communications over a distance - as well heat for tempering wooden weapons and tools. In most parts of Australia the Aboriginals relied more on fire than on clothing to remain warm in the winter, and even carried fire-sticks for personal warmth while on the move (ibid,72). Fire was also used to control the immediate environment of the campsite. It would drive away snakes from long grass, and in northern regions of Australia, the smoke would keep mosquitoes at a distance (ibid 71,146). Controlled, localised fires were used for felling trees or, burning on a bed of damp clay, for warmth and light in fishing canoes at night. The Aboriginals sometimes used large scale burning to encourage rapid regrowth of grassland, and so increase the efficiency of food production (ibid,77). Fire was also used on occasion in food collection, to surround animals and drive them towards the hunters.

The Aboriginal energy system was successful to the extent that it sustained an estimated population of about 250,000 in southeastern Australia in 1788 (Butlin 1984,147), at a standard of living comparable with Europe at the time:

> "If we specify the main ingredients of a good standard of living as food, health, shelter and warmth, the average aboriginal was probably as well off as the average European in 1800"(Blainey 1982,225).

For all its refinements in food gathering and in the use of fire, however, the key limitation of the Aboriginal energy system was its diffusion. It could sustain neither the concentration nor the rapid growth in population which characterise the urban energy system. The density of Aboriginal population matched the density of the native food resources. In coastal regions with good food supplies, such as Sydney, the Aboriginals might be "semi-sedentary, with established settlements and a 'permanent' population" (Butlin 1984,164). Regions with less reliable food supply were without permanent settlement. Significant concentrations of population were limited in frequency to abundant years, limited in size to several hundred, and limited in duration to about a week (Blainey 1982, 29).

It is estimated that the total Aboriginal population of the Sydney region in 1788 was between two and three thousand (Kohen and Lampert 1987,345). By 1881, on the eve of electrification, the Sydney energy system sustained a permanent population of about 247,000, or about the size of the entire Aboriginal population of southeast Australia at the time of British settlement. Among the economic, cultural and technological forces which the British settlers brought to Australia was an energy system which was the antithesis of the Aboriginal. "People who could not boil water were confronted by the nation which had recently contrived the steam engine" (Blainey 1982,253).

### The Energy Technology of the Settlers

The settlers left Britain with some knowledge of the technology which was changing the conditions of life in what was then the most industrially advanced nation on earth, and applied that knowledge in Australia to the extent of their limited resources. They were kept informed of new developments as quickly as the communications of the time allowed, by despatches and by the arrival of immigrants, many of whom brought new machines and processes with them.

The mechanisation of labour was one of the major technological advances in eighteenth century Britain. The machinery itself was designed to be operable by any source of energy capable of turning a shaft: men or horses walking in a circle, water wheels or wind vanes. Equipment of this kind was cheap for the British authorities to send to Sydney, relatively simple to assemble, and many of the components could readily be fabricated from local materials. Accordingly, Sydney's earliest power technology was based on the energy of wind, water and convict labour.

Initially the colony's entire power system was directed to the task of milling imported and locally grown grain. The first fleet brought out 40 iron hand-mills, each operable by four men (Selfe 1902,96). Productivity increased with the construction of experimental mills using up to nine men each. Nevertheless the lack of effective milling capacity became critical by early 1795 (Linge 1980,43). The first windmill in the colony, assembled from imported components, relieved some of the pressure after its completion in early 1797 (Selfe 1902,99). The colony's first water mill was built at Parramatta in 1804 (HRA I/IV,467) but did not operate satisfactorily for some years (Linge 1980,43).

Water was still the main source of power in Britain in 1788 (Singer et al IV,151). The general use of the steam engine for rotative power (as distinct from its earlier application in mine pumping) increased rapidly from about that time (ibid,183). The initial advantage of the steam engine over wind and water was not greater power but greater flexibility and reliability. Being independent of the limitations and caprices of the geo-energy system, it could provide power in any place and at any time so long as fuel was available.

Between 1788 and 1815 sucessive improvements in energy technology raised the productivity of milling in Sydney 40 fold (see Table 2.1). Even so, the colony's effective milling capacity more than doubled when Sydney's first steam began grinding grain in June 1815.[1] It used first wood and then coal for fuel (Ellis 1969,18). No more steam engines reached the colony during the following decade, during which period several more wind, water and horse-mills were built, mainly in the expanding townships outside Sydney and Parramatta (Linge 1980,92).

After 1825 Sydney became increasingly familiar with steam technology. Stationary engines and steam ships arrived at an increasing rate. The first steamship to be built in Australia, using an imported engine, was launched on Sydney Harbour in 1831 (SG 28.4.1829,Andrews 1975,10). Local iron workers were able to repair engines from 1828 (SG 4.7.1828) and to manufacture entire engines from 1836 (Walsh 1963,48).

The colony's thermal energy technology was simple. Heat was applied on a relatively large scale to brickmaking kilns, vats for salt water boiling, brewing or tallow rendering, and distilleries (ibid). Household technology was the most primitive of all. The transition from the open cooking cooking grate to the enclosed range was accomplished in wealthier British homes between 1780 and 1840, via a number of patented innovations (Yarwood 1983,60). Several more decades passed before they diffused to Australia. The major household energy source in Sydney was the open or semi- enclosed kitchen fire. It provided energy for cooking, and heated whatever water was necessary for bathing or laundry. The earliest houses consisted of a single unpartitioned room, so "more often than not the kitchen was the whole house" (Irving 1987,233). In the more elaborate style of house built before the 1850s the kitchen tended to be partly or completely detached, as a precaution against fire, and to remove a source of heat which was unwanted for much of the year (Evans 1983,34).

Once the living areas became separated from the kitchen fire, some form of room heating, usually a simple open hearth fire, became necessary even in the mild Sydney winter. Light was provided by the open fire, by candles or by portable lamps burning vegetable or animal fats. Oil lamps of varying power and sophistication also provided limited lighting in the main public spaces, until the introduction of gas in 1841.

The first public exhibition of the practical use of coal gas for lighting and heating was given in Paris in October 1801 (Singer 1958 IV,258). The first commercial development of the technology took place in Britain, where the increasing price of lighting oils and the demand for a safer illuminant in factories made conditions particularly favourable (ibid,265). Coal gas reticulation took a path which electricity was to follow 80 years later. The technology was rapidly scaled up from an experimental single-house installation to a cotton mill in 1806, and by 1812 to urban dimensions (ibid). The role of coal gas as a commercial urban illuminant was pioneered by Freidrich Winsor, whose gas company commenced operation in London in 1812. He grasped the essential economics of gas reticulation, much as Edison was to do with electricity nearly 80 years later:

> "From the first he realized that the Boulton and Watt idea of installing gas mill by mill and house by house was unsound. He saw that consumers would have to be supplied through mains radiating from central gas-generating stations. He realized, too, that the amount of capital required for such a purpose would be beyond the resources of any single individual or group of capitalists. It would be essential to obtain a charter from Parliament to form a joint stock company with limited liability" (ibid,268).

Gas was a superior and more convenient illuminant, it could be manufactured centrally and readily reticulated and, given a sufficient density of demand, it was economical. Its introduction required initiative, capital and the sanction of Parliament. It was also a powerful symbol of civic progress and 'improvement' (Briggs 1968,218). The first recorded experiments with vapourised oil illumination in Sydney took place in 1828 (SG 30.5.1828). The first recorded attempt to form a company to reticulate coal gas was made in December 1834, but the project collapsed in 1835 (Ginswick 1959,231). Regular gas lighting of a public wharf commenced in the same year.[2] Gas reticulation was first undertaken by the Australian Gas Light Company, the formation of which in 1837 is documented by Ginswick (1960) and Broomham (1987).

Until the railway between Sydney and Parramatta commenced operation in 1855, all land transport in the colony was animal-powered. Before the 1800s, when horse-drawn carts and waggons began to offer commercial carriage within the town, settlers used handcarts to transport timber and other goods around the settlement (Stringer 1980,18). Sydney was compact enough for many journeys within the town to be made by foot, but as the 19th century progressed, a greater proportion of trips came to be made on horseback or in horse-drawn vehicles.

Land transport between Sydney and other settlements was also animal-powered, and the poor condition of the roads made the task slow and labour-intensive. Where speed was not criti cal, bullocks were preferred to horses, because of their lower purchase price and feed costs. Each animal consumed half the daily rations of a horse, and could obtain its feed at the side of the road. Horses required a daily ration of 30 lbs of wheat straw, oats, bran and cultivated hay, the haulage of which reduced the commercial carrying capacity of horse transport (Blainey 1967,123). The energy embodied in a bullock could also be recovered: as a last resort, the animal could be eaten. The energy required to transport a given mass was less by water than by land, particularly if the land route was steep and the roads badly made. Furthermore the cost of each unit of transportation energy was low if wind was the source, as it was for all colonial navigation until the 1830s. Consequently, freight rates per ton-mile were five to ten times higher overland than by sea, and delivery was slower (Linge 1980,76).

## Local Energy Resources

Firewood was the most readily available of Sydney's energy resources. As land was cleared to accommodate the town's growth, the best timber was used for building and the rest as fuel. It is probable that firewood supplied more energy in Sydney than any other resource in the first century of the town's existence, but the quantity cannot be reliably calculated: it was so common that it drew comment in public records or the press only when scarce or expensive. Firewood was freely obtainable near Sydney until the 1820s:

> "As Sydney grew larger fuel became an added item of expense. In the early days sufficient wood could be gathered by every one, but during this period [after 1820] it was necessary to purchase it. A load of about three-quarters of a ton cost 5s. Wood was the ordinary fuel of all classes, but coal was also used..." (Coghlan 1918, 287).

Since coal could be obtained from Sydney fuel merchants for about 20s per ton in the 1820s (SG 3.6.1824), wood was one-third the cost for the same weight, or between two thirds and equal cost for the equivalent amount of energy. As a commercial commodity, therefore, wood was little cheaper than coal. Its attraction lay in getting it free where possible, whether for own use or for resale, and by 1822 the government found it necessary to issue public warnings against cutting timber on Crown lands near Sydney (SG 28.6.1822).

Although the site of Sydney had been selected for its safe anchorage, its fertility and its water supply, it was also fortunately located for wind power. There were several suitable windmill sites on the ridges above the town. After the government built the first windmill in 1797 their number increased steadily, to a maximum of 10 in 1831.[3] Water power was first successfully exploited at Parramatta in 1805, but in Sydney itself it was less used than wind because of the shortage of suitable sites. The first water mill near the town commenced operation in January 1812, at Barcom Glen in what is now Paddington (SG 18.1.1812,25.12.1813). By 1824 there were 3 water mills in the Sydney police district, the maximum number recorded (Linge 1980,766,SG 21.10.1824). Wind and water power were exploited primarily to meet the demand for grain milling.[4] In contrast to the integrated industries later established later around coal and steam, the mills formed a loose network which shared little apart from a common technology and a common purpose. They were built, operated, maintained and frequently resold by small entrepreneurs who in most cases owned no other businesses.

Perhaps the greatest impetus to the rapid modernisation of the Sydney energy system lay in the settler's awareness of the value of coal. The first discoveries of coal in NSW are recorded in the contemporary accounts of Collins (1798) and in the governors' official despatches to the Colonial Office. Between 1791 and 1797 coal was found both to the north and south of Sydney by fishermen, shipwrecked sailors and escaped convicts. After sending back reports and samples to England, Governor Hunter received instructions in 1798 to mine the coal for export to the Cape of Good Hope (HRA I/II,113,242).

The southern coal seam outcropped in a cliff overlooking the sea with no sheltered harbour nearby, and proved too difficult to work. The northern coal deposits were more fortunately located. They were accessible by drift mining and near a safe harbour which made loading possible. They were also near the supply of fresh water necessary to support a permanent mining settlement, from a river which came to be called the Hunter. Hunter district coal was first shipped to Sydney in mid 1799, and may have been exported in the same year (Ellis 1969,7). The industry's development in its first decade was erratic. The export trade was depressed by the Anglo-French war (HRA I/V,n3) and output was governed by a modest demand in Sydney, largely for the government's own purposes. Public demand was constrained by the level of government duty, and stimulated by its removal in 1823 (Bigge 1823,93,HRA I/XI,100).[5]

As firewood became more scarce in the 1820s, coal assumed greater importance in the Sydney energy system. By 1824 several merchants were advertising coal for sale (SG 3.6.1824). In 1823 the British government directed the local authorities to give private capital a greater part in coal production. After some resistance from local merchants, a 31 year lease on the Newcastle mine was granted to the Australian Agricultural Company (AAC) which had been formed in London in 1824 to exploit the resources of the colony (Coghlan 1918,231). The AAC was to have a monopoly on coal production so long as it did not "impose an exorbitant price upon the Coal" (HRA I/XIV, 274). The mine was transferred to the AAC at a time when domestic NSW demand for coal was increasing rapidly with the arrival of more steam engines, particularly steamships, in the colony. Table 2.3 shows that NSW per capita coal consumption increased nearly tenfold from 1822 to 1841. Export demand rose more slowly. It amounted to nearly a quarter of production in 1828 but less than 6% in 1841.

Animal and vegetable oils were the principal lighting fuels in the colony until the introduction of coal gas in 1841. The demand for lighting oils, particularly for export to Britain, led to the early establishment of the important whaling and sealing industries and then in the 1830s the tallow industry. Whaling and sealing first began off the NSW coast in 1791. The growing export trade was badly affected by the imposition in 1810 of a British levy on colonial oil, a fall in the price of sealskins, and the over-exploitation of the most accessible waters (Linge 1980,27). The industry recovered as population and investment in the colony increased, and as ships became available to exploit more distant waters. By the 1830s, the industry was contributing 35-40% of the total value of the colony's exports (Linge 1980, 89). Its peak year was 1840, after which it declined rapidly: by 1850 it contributed only 3% of the value of exports, and by 1860 it had virtually disappeared (Coghlan 1918, 509).

The amount of oil retained for lighting in the colony is difficult to determine, since neither import nor export quantities are clearly defined in the statistics (Linge 1980,89,93). By the mid 1820s several local oil and lighting merchants were advertising in the Sydney press and the government was able to call regularly for competitive tenders for the supply of "common and sperm oil" (SG 1.4.1824). The manufacture of tallow candles was another early industry of the colony (Walsh 1960,28), often associated with tanning and soap making. In 1828 Governor Darling reported:

> "The greater proportion of Candles for internal consumption are also manufactured within the Colony, chiefly at Sydney, but also by individual settlers for their own use."(HRA I/XIV,129).

Until the 1830s a majority of adults in the colony were convicts. This pool of labour represented an important energy resource, which the government retained for public works, or assigned to private employers "...to clear the ground, build houses, and do such other work, both mechanical and domestic, as might be required" (Coghlan 1918,24). Convicts on assignment were kept at the expense of their employers, some of whom paid them almost as much as free labour, and some of whom treated them as slaves (Linge 1980,56). Assigned convicts represented a valuable subsidy of labour costs by the government, and were in great demand by entrepreneurs (ibid,29). The ratio of convict to free adults in the colony between 1821 and 1846 is shown in Table 2.3. The ratio varied from year to year but remained close to 1 until 1833, then declined steadily to 0.27 in 1841 (the year following the abolition of transportation) to 0.03 by 1846 (ibid,54).

The assignment system allowed the NSW government to selectively subsidise particular industries and regions. During the 1820s the British government repeatedly instructed the local administration to assign convicts to the country rather than the towns (ibid, 56), a policy which favoured the influential pastoral interests. Table 2.3 shows that the policy of dispersal was implemented: the ratio of convicts to free settlers in Sydney was always considerably lower than in the rest of the colony, and declined rapidly after 1828.

The comparative shortage of convict labour had considerable impact on the Sydney energy system, particularly as the ratio of horses was also much lower in Sydney than in the colony as a whole (RC 1827-29). The effect was not so much on the direct supply of power, for which convict labour was rarely used in any part of the colony once wind, water and horse mills became available, but rather through the effect of convict labour on the relative cost and availability of firewood, coal and even feed for horses:

> "In the town of Sydney, where the principal demand for it exists, the supply of food for horses has been obtained by the extra labour of convicts, who procure grass from the banks of the Parramatta River" (Bigge 1823,19).

The shortage of convict labour for gathering firewood was one factor in the ready adoption of coal to meet the energy requirements of government establishments in Sydney (HRA I/III,324), and probably a reason for committing convict labour to the development of the mines in Newcastle. The immigration of free workers increased, but skilled labourers and domestics remained in such short supply in the 1830s that they could command wages high by British standards (Coghlan 1918,201). Wage rates fluctuated with economic conditions and immigration rates, but the underlying trend was upward. This contributed to the adoption of labour-saving technologies, and hence to the further development of energy resources.

## The Role of the Government

One consequence of Sydney's origin as a penal colony of 700 convicts and 330 officials and militia was that every aspect of the settlement, including the energy system, was initially under the direct control of the military governor. The steady arrival of free settlers and the release of convicts gradually reduced the proportion of the population directly dependent on the government to about 30% by 1815, but the government sector and the administrative decisions of the governor continued to dominate and distort the NSW economy until much later (Linge 1980,25).

The first energy concern of the government was food: obtaining it over long supply lines, catching or growing it locally where possible, and processing it. The government determined the course of early techno-energy development by building the first wind and water mills to process grain, and from time to time decided the most efficient deployment of the colony's various energy resources. When distillation first began in 1794 the governor at first prohibited the industry for the most fundamental of energy reasons: the 6 lbs of wheat required to make a single pint of spirits could also make enough bread to feed a convict for ten days (Linge 1980,41).

In 1801 Governor King found it necessary to regulate and impose duty on the growing traffic in coal from Newcastle to Sydney (HRA I/III,168). He also attempted to substitute coal use for wood in the military barracks, not because of any absolute shortage of wood but the shortage of convict labour for gathering it (HRA I/III,326,342). In 1804 he decentralised much of the energy demand for feeding government dependents to the household level, by issuing rations as flour rather than as bread baked in the public ovens:

> "Among the convicts victualled by the Crown there are but few...who have not comfortable little dwellings at the places they are stationed at; many have the convenience of small ovens, or iron pots, they bake under; and not a few have their wives and families of children, who they maintain by their labour when their government work is finished..." (HRA I/IV,467).

Coal and wood were used interchangeably during the 1800s, partly in response to the variations in coal price caused by the imposition and removal of Government duty (HRA I/VI,153). Between 1815 and 1822, however, the increasing scarcity of wood again prompted the government to press for coal substitution:

> "Wood will no longer be issued as Fuel to the Troops, Public Departments, or individual Officers of Government...it being intended to issue Coals in future as Fuel, on Account of the very great Expense and Inconvenience experienced hitherto by government in supplying Fire-Wood" (SG 2.9.1815, HRA I/X, 670).[6]

The substitution of coal for wood represented a deliberate diversion of convict labour from a diffuse energy resource to a concentrated one, substantially increasing the overall efficiency of the energy system. There were also other incentives for the government to promote coal. It controlled every aspect of the resource: the rate of mining, the price at Newcastle, and dues on export and local consumption. The more coal produced, the more revenue the government derived. In due course the government's coal monopoly was replaced by the private monopoly of the AAC. In 1828 the British colonial secretary instructed Governor Darling to maintain the labour support to the mine "so that no scarcity of this Article may take place" (HRA I/XIV, 273). The AAC duly received preference in the assignment of labour. By 1835 the ratio of convicts to free labourers at its Newcastle establishment was nearly 13:1 (HRA I/XVIII,134), 17 times the average for the colony (see Table 3.2). The effect of this was an annual subsidy by the government equivalent to about 40% of the average selling price at the pit head in 1836.[7]

In 1827 the government commenced regular illumination of Sydney's major streets through the agency of private contractors (McGuanne 1900,4). It bore the expense grudgingly, and resisted the frequent public demands for extension of the service beyond the central area (SMH 18.2.1831). Street lighting became one of the issues on which the eventual incorporation of the City of Sydney in 1842 revolved (Larcombe 1973 I,21). The government's desire to rid itself of the cost of street lighting also played a part in Governor Bourke's support for the establishment of AGL:

> "I am the more readily disposed to solicit such an encouragement for this Company, as its formation may tend to promote habits of co-operation in measures of public improvements which are at present much wanting here, the Colonists having been hitherto accustomed to lean upon the Governmment for everything" (HRA I/XVIII,557).[8]

The government was not as generous to AGL as it had been to the AAC, however; it was by then trying to diminish its direct role in the Sydney energy system.[9] The wind, water and coal industries all passed into private hands by the 1830s. The direct subsidy of the coal industry ceased in 1841 with the abolition of the convict assignment system, though the AAC's monopoly was permitted to remain until 1847 (HRA I/XXV,448).

### Sydney and its Energy System in 1841

Sydney had started as a colonial beach-head and a penal camp, but by 1841 it was the administrative, commercial and manufacturing centre of a wide area of settlement. Its boundaries were fixed in 1837 by the colonial legislature (which had included appointed legislative councillors since 1823, and was on the point of including elected representatives) and in 1841 the township's imminent incorporation attracted considerable public discussion. The government favoured incorporation as a means to reduce costs by passing on municipal functions such as street lighting to local bodies. This was not welcomed by some Sydney residents, since costs which were then paid from the general colonial fund would have to be borne by rates (Larcombe 1973 I,27). Others supported it as a means for obtaining, and in AGL's case of selling, urban services: the company needed a body with which to contract for street lighting (SMH 7.5.1842).

The proportion of the NSW population resident in Sydney had declined in the first decades of the century, as settlement began to diffuse through the rest of the colony. By 1841 it had stabilised at about 28%, where it remained with minor fluctuations until the 1880s (Linge 1980,71). The 1841 census gives the population of Sydney as 35,507 (RC 1841), 29,973 of whom lived within the town boundaries fixed in 1837. The Sydney and NSW economy was booming, fuelled by easy credit and the speculative imports of luxury goods in the late 1830s (Coghlan 1918,477). Sydney's economy was based on commerce, on servicing the expanding wool industry, and on the whaling industry which was then at its peak. A number of industries had developed to serve the local population with basic items, and to supply the growing towns of the interior with capital equipment for their own development, including iron castings and locally built steam engines.

The proportion of retailers, domestic servants, and mechanics and artificers (which includes building tradesmen, craftsmen and industrial workers) was far higher in the Sydney workforce than in the rest of the colony, as Table 2.4 indicates. The population of the town also had a greater percentage of women and children and a lesser percentage of convicts. Its household structure as well as its economic structure were more modern and urban.

The range of fuels and end uses in the Sydney energy system in 1841 is illustrated in Figure 2.1. The high value of lighting as an energy service was reflected in market prices. In 1841 a pound of locally made candles, enough to provide a single light for a week, cost 4d (Coghlan 1918,465) or about 30 times the cost of an equal weight of coal. A gallon of common whale oil gave better quality light at a cost about 1s per week (SMC 1843). The cost of an equal amount of light from the new illuminant, gas, was estimated to be double that of oil though the quality was considered superior (ibid). Perhaps because of these high prices Sydney was still sparingly lit. Until the introduction of gas street lighting in 1842 the brightest sources of outside illumination were probably the numerous public houses, with their private gas lamps, and the occasional lamp-merchant's shop window.

Industrial power was provided by water, wind and coal. The combined power of the two water mills and seven windmills still in operation would barely have exceeded that of the smallest of the seven steam engines. Wind and water mills had served their purpose and their numbers were slowly declining. Those nearest the centre of the town were under pressure from urban development. Rising land value made them uneconomical and increasing building density began to alter the geo-energy flows on which they depended. Sydney's steam power was devoted excusively to flour milling until 1841, when the first steam sawmill commenced operation.[10] There was also considerable thermal energy demand from brewing, brick-firing and forging, but the colony's most energy intensive industries, lime burning and salt evaporation, were located at Newcastle near the coal fields. Most industrial activities in Sydney were still carried out with hand tools and small heat sources.

Energy requirements were becoming a major factor in industrial location. Small deliveries of fuel could be made anywhere, but the relatively large amounts required by steam engines and other energy-intensive industries made a waterside location preferable. The availability of fresh water was a further constraint on steam engine location; reticulation of water did not commence until 1844 (Aird 1961,6). The water and wind mills were of course restricted to the few naturally suitable sites. The locations of the main power sources, and the extent of the gas reticulation system in 1841, are shown in Figure 2.2.

Firewood still made up much of the fuel supply, but by 1841 its use was becoming restricted to the domestic sector. While small quantities could still be gathered by users at the edge of the town, the importation and distribution had become more formalised through carters and fuel merchants. Coal was freely available through a well developed distribution system, and was supplying an increasing proportion of Sydney's domestic thermal energy as well as almost all industrial, commercial and government demand.[11] Coal was the most versatile of the energy sources in use. It was the only one capable of supplying heat, power, mobile power (via steamships) and lighting (via coal gas).

At a time when horse mills were still common in the rest of the colony, the use of animal power in Sydney was largely restricted to land transport. Most stationary tasks at work or in the home still relied on human labour, albeit with some mechanical assistance: the efficiency of operations such as lifting, water raising and turning was sometimes increased by pulleys, pumps and treadles. Most of the ferry traffic between Sydney and the growing settlements at North Sydney, Pyrmont and Darling Point also relied on human effort, in the form of oarsmen.

As the energy system became more clearly defined, so did the main interests involved in it. Many aspects of the system were still controlled by the government of the colony, and indirectly by the British government, but their role was becoming less central. Local private capitalists and entrepreneurs were also involved as both energy producers and consumers. The major investment of private capital in the colony's energy system was still the AAC's coal mine. In addition, several small coal mines also operated in the colony in defiance of the AAC, helped by the growth and decentralisation of coal demand brought about by steam navigation.

The largest private investment in the Sydney energy system was AGL's.[12] Also interested were the numerous carters and merchants who made a living from supplying fuel and light, and of course the consumers. Some of the industrial consumers of coal were large enough to purchase directly from the mines and bypass the coal merchants, but apart from this the scope for minimising fuel costs was limited. The state of technology restricted specific fuels to specific applications: there was little direct competition between energy forms.

In 1841 the Sydney energy system was in transition from its formative stage to a level of development almost the equal of any British city. Apart from the railway, all the energy technologies of the time had been introduced: gas within 25 years of its appearance in London, and at a much earlier stage of urban maturity. Energy-intensity, however, was not high in comparison with the industrialised cities of the time. Sydney had about one sixth the number of steam engines in Birmingham and one quarter the steam power per capita.[13] Furthermore, only 10% of the steam power in Birmingham was used for milling flour, and fully 80% was used in metal-working and other manufacture (Singer et al 1958 IV,166). Sydney, with its steam power devoted almost exclusively to flour milling, was not yet an industrial city.

**FIGURE 2.1**
**SCHEMATIC DIAGRAM OF THE SYDNEY ENERGY SYSTEM**
**1841**

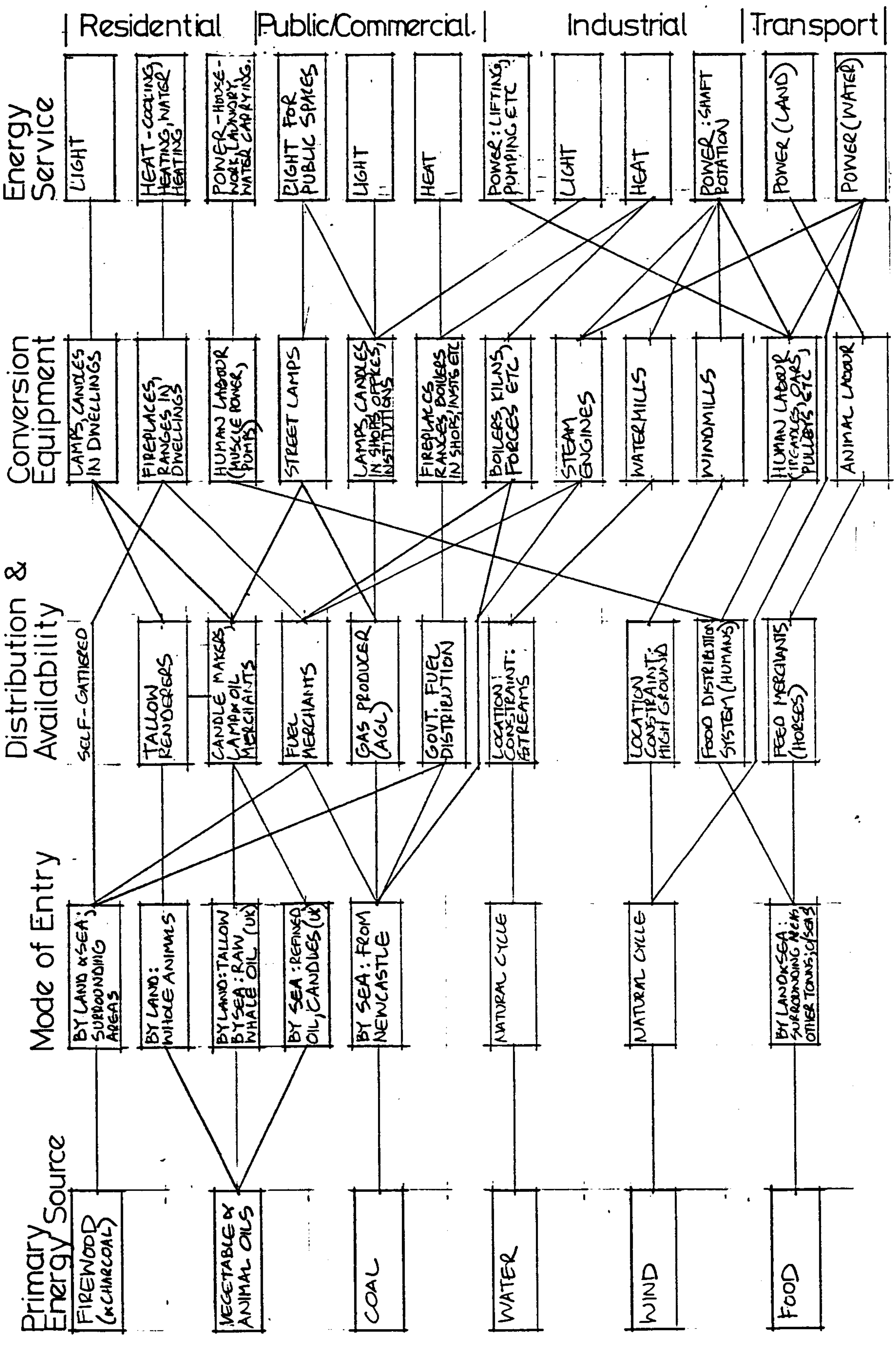
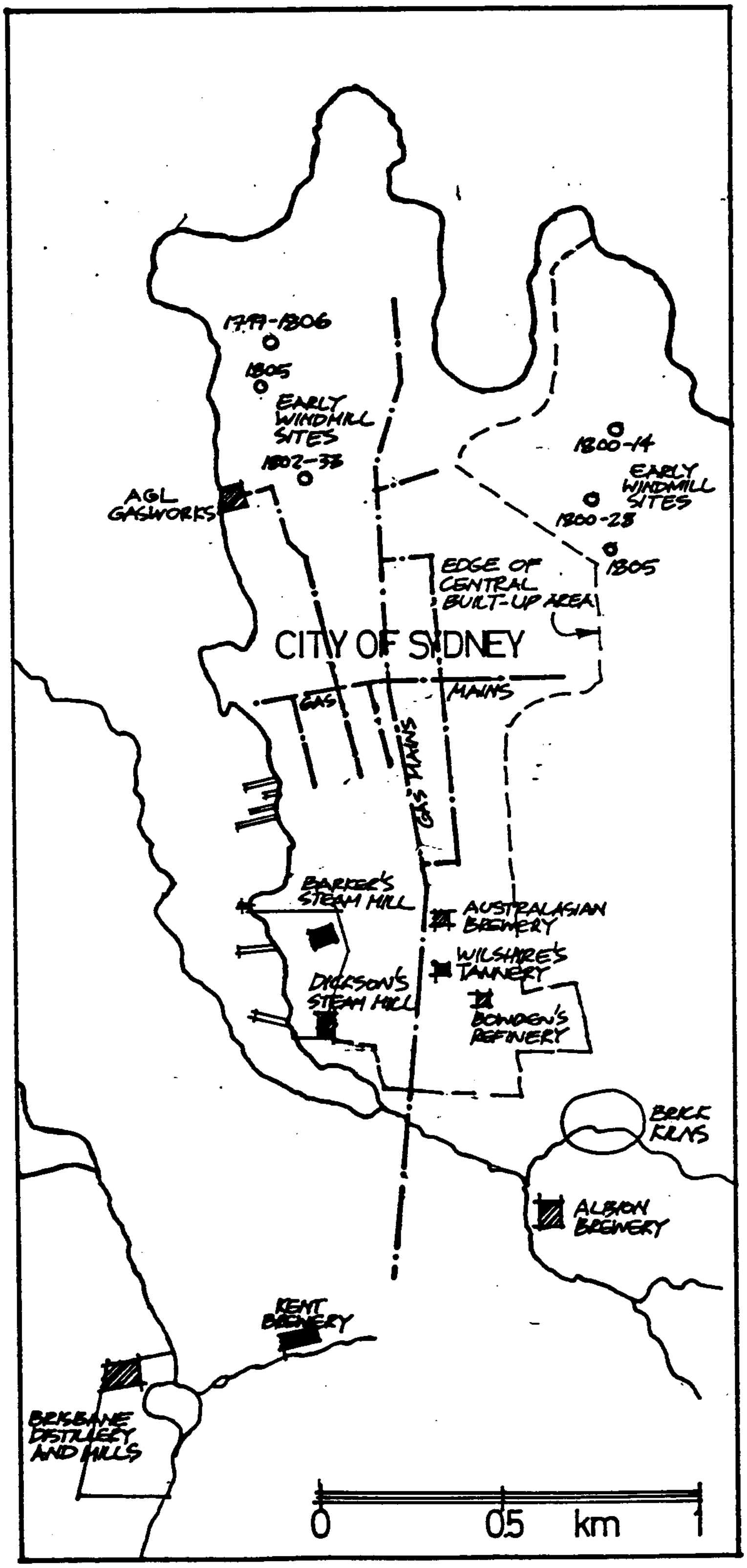


**FIGURE 2.2**
**LOCATION OF MAIN POWER SOURCES AND EXTENT OF GAS RETICULATION**
**SYDNEY 1841**




(SOURCES: GINSWICK 1960, WALSH 1963)

**TABLE 2.1**
**ESTIMATED OUTPUT OF EARLY GRAIN MILLS**
**SYDNEY AND PARRAMATTA**
**1788 - 1822**

| YEAR | MILL AND LOCATION (S Sydney, P Parramatta) | POWER SOURCE | EST. POWER (HP) | HOURLY PROD. (lbs)(a) | DAILY PROD. (lbs/man) |
|---|---|---|---|---|---|
| 1788 | Iron mill, S | 4 men | 0.16(b) | 45 | 110(c) |
| 1794 | Baughan's capstan mill, P | 9 men(d) | 0.60(b) | 168 | 190(e) |
| 1797 | First govt. windmill, S | wind | 1.0 | 280(f) | 1400(j) |
| 1805 | First govt. watermill, P | water | 1.1 | 300(g) | 1500(j) |
| 1815 | Dickson's steam mill, S | coal | 4.0 | 1120(h) | 4500(k) |
| 1820 | Horse mill, P | 2 horse | 0.6 | 160(i) | 780(j) |

a. Assuming 10 hr work day in each case.
b. After Rankine & Aubuisson (OHT V,159).
c. Linge 1980,43.
d. Selfe 1902,98.
e. Assuming man mill described by Linge is Baughan's mill.
f. Linge 1980,43; Selfe (1902,93) gives higher capacity: mill could grind a bushell of grain every 10 minutes, giving about 380 lbs/hr.
g. ibid.; SG 17.2 1805 gives 6-8 bushells of grain per hour.
h. ibid. 82: daily capacity of 5 tons of flour.
i. ibid.
j. Assuming 2 attendants.
k. Assuming 5% efficiency, daily coal requirement is 0.2 tons of 10GJ/tonne coal. Mining rate reported by Bigge (1823) was about .75 tons per day, say half as much when labour for carriage etc to Sydney included. Therefore steam engine fuel requirement would have kept a further man half employed in addition to its (assumed) two attendants.

**TABLE 2.2**
**COAL PRODUCTION, EXPORTS AND DOMESTIC CONSUMPTION**
**NSW 1822 - 1901**

| YEAR | PROD. | EXPORT ('000 tons) | DOMEST. | SYDNEY POP ('000) | tons/ cap(d) | NSW POP ('000) | tons/ cap |
|---|---|---|---|---|---|---|---|
| 1822 | 0.9(a) | 0.1 | 0.8 | 8.1 | 0.10 | 29.7 | 0.03 |
| 1828 | 4.0(b) | 1.0 | 3.0 | 10.8 | 0.28 | 40.1 | 0.08 |
| 1836 | 12.6 | 1.7 | 10.9 | 19.7 | 0.37 | 78.9 | 0.14 |
| 1841 | 34.0(c) | 2.0 | 32.0 | 35.5 | 0.45 | 145.3 | 0.22 |
| 1851 | 67.5 | 28.5 | 39.1 | | | 187.2 | 0.21 |
| 1861 | 342.1 | 208.0 | 134.1 | | | 357.4 | 0.38 |
| 1871 | 898.8 | 565.4 | 333.4 | | | 516.7 | 0.65 |
| 1881 | 1769.6 | 1039.0 | 730.6 | | | 777.0 | 0.94 |
| 1891 | 4037.9 | 2514.4 | 1523.6 | | | 1153.2 | 1.32 |
| 1901 | 5968.4 | 3471.0 | 2497.4 | | | 1375.5 | 1.82 |

Sources: RC, JCB 1939 (coal production) ABS 1987c (population)
a. "sold at Newcastle"
b. "estimated produce of 2 mines"
c. 32761 tons by AAC; est 1200 tons from "one other mine on Lake Macquarie.
d. Assuming all coal is used in Sydney before arrival of steam ships in 1830s, 66% in 1836 and 50% in 1841.

TABLE 2.3
RATIO OF BOND TO FREE LABOUR
SYDNEY AND NSW
1822 - 1851

| YEAR | % ADULT POP,NSW (a) | | | % TOTAL POP,NSW (b) | | | % TOTAL POP,SYDNEY (b) | | |
|---|---|---|---|---|---|---|---|---|---|
| | FREE | BOND | Bond/ Free | FREE | BOND | Bond/ Free | FREE | BOND | Bond/ Free |
| 1822 | 49.1 | 50.9 | 1.04 | 55.5 | 44.5 | 0.80 | 64.6 | 35.4 | 0.55 |
| 1828 | 45.8 | 54.2 | 1.18 | 57.2 | 42.8 | 0.75 | 68.9 | 31.1 | 0.45 |
| 1836 | 57.0 | 43.0 | 0.75 | 63.9 | 36.1 | 0.56 | 82.2 | 17.8 | 0.22 |
| 1841 | 78.6 | 21.4 | 0.27 | 79.4 | 20.6 | 0.26 | 89.7 | 10.3 | 0.11 |
| 1846 | 96.9 | 3.1 | 0.03 | 94.2 | 5.8 | 0.06 | 98.1 | 1.9 | 0.02 |
| 1851 | | | | 98.6 | 1.4 | 0.01 | 99.9 | 0.1 | 0.00 |

a. Calculated from Linge 1980,55. Table 3.1.
b. Calculated from RC; all population, including children, and slightly different area basis: all colony up to 1841, then NSW only.

TABLE 2.4
POPULATION AND WORKFORCE AT THE CENSUS
SYDNEY AND NSW
1841

| OCCUPATION | SYDNEY(a) NUMBER | % | REST NSW NUMBER | % | TOT NSW(b) NUMBER | % |
|---|---|---|---|---|---|---|
| Landed proprietors, merchants bankers, professionals | 562 | 1.9 | 3915 | 4.0 | 4477 | 3.5 |
| Shopkeepers and other retail | 785 | 2.6 | 989 | 1.0 | 1774 | 1.4 |
| Mechanics and Artificers | 3754 | 12.5 | 6961 | 7.0 | 10715 | 8.3 |
| Shepherds and others in the care of sheep | - | - | 12948 | 13.1 | 12948 | 10.1 |
| Gardeners, stockmen & persons employed in agriculture | 435 | 1.4 | 16235 | 16.4 | 16670 | 13.0 |
| Domestic servants | 2657 | 8.9 | 7168 | 7.3 | 9825 | 7.6 |
| All other persons(c) | 21780 | 72.7 | 50537 | 51.2 | 72317 | 56.2 |
| TOTAL | 29973 | | 98753 | | 128626 | |

Sources: RC, Mansfield 1841
a. Within boundaries of Township of Sydney as defined by Act IV of William IV 1937 (Mansfield 1841,49).
b. Including Port Phillip, Norfolk Island, Moreton Bay, Port Macquarie; note that Tables 3.2 and 3.3 use different area bases and are not comparable.
c. Includes women, children and convicts in government employment.

## 2.2 MECHANISATION AND ENERGISATION

Between 1841 and 1881 the population and prosperity of Sydney increased dramatically. The gold rushes of the 1850s stimulated the city's growth but also dislocated the supply of labour and resources to many of its industries. Growth slowed in the 1860s, but the early 1870s began a 15 year boom period of rapid expansion in industry and commerce (Coghlan 1918,869,1231). Sydney's social processes became more organised, its physical processes more mechanised and its environment more controlled. The associated trends in energy technology and energy service demand were well established by the introduction of electricity in the 1880s. Indeed, they created an energy system favourable to electrification.

### The Impact of Technology

The impact of technology on daily life in the industrialising countries accelerated during this period. Information about new technology was rapidly conveyed to Australia by new forms of communication. Sydney was linked to the outside world by the growing international steam ship traffic and, from 1872, by the intercontinental telegraph. Communications within the city also improved. The Sydney Morning Herald installed the first steam printing press in Australia in 1853, enabling its circulation to rise from 1,000 to 6,000, larger than most London papers of the time (Cannon 1975,125). Several illustrated journals also began publication in the 1870s. The detailed press reports of the great international exhibitions, from the London Great Exhibition of 1851 and the Sydney International Exhibition of 1879, popularised the many new developments in energy technology.

Steam was the dominant power source. Steam engines became more common and more adaptable: the stationary engine developed many variants, and locomotive and marine engines became areas of specialised design. The single cylinder Cornish beam-engine remained the preferred design for large power applications such as water pumping, which commenced at Botany in 1859.[14] The development of small power horizontal and vertical engines, many of them locally made, took steam into more Sydney industries. By 1876 the Sydney firm of P.N.Russell & Co was advertising that it could supply from stock engines of 2 to 25 hp, and build engines of up to 200 hp (ISN 6.12.1876).

The wide availability of steam engines helped change the relationship between power plants and manufacturing processes. Before 1841 Sydney's power-intensive industry was clustered around the few water-mills and steam engines in the town, but in this period steam powered industries were established at many locations. Local power distribution systems evolved in the larger manufacturing establishments. Several small steam engines were sometimes fed from a common boiler, or power from a central engine was transmitted by increasingly elaborate systems of gears, belts and ropes (Singer et al 1958,V,132).

The internal combustion engine was also introduced during this period, and gained some success as an alternative to the smaller stationary steam engine, well in advance of its use in transportation. The gas engine was first patented in France in 1859 ibid,158), and by 1874 one had been installed as a winch engine in a Sydney woolstore (Balint et al 1982,122). Though more expensive to buy and to run than steam engines, gas engines were compact, did not need stoking and used a fuel already reticulated in many parts of Sydney. They were adopted for the same reasons and for many of the same applications as the electric motors which succeeded them: small, controlled power applications within city buildings.

The demand for specialised energy services such as lifting and wool-pressing led to the development of a number of power reticulation systems within commercial buildings. Hoisting services were initially provided by gas or coal fuelled steam engines, through the action of direct mechanical drives (Selfe 1894, 14). By 1881, however, several lift installations in Sydney were using hydraulic systems, which transmitted power from the engines to the lifts through pumps and accumulators (ibid,19).

The trends in heating technology paralleled those in power: increased control at both high and low energy levels, and a tendency to locate the heat source at the task rather than the task at the heat source, as before. Steam was also introduced as a heating medium in industrial processes, particularly where inflammable materials were involved. Super-heated steam was used in NSW kerosene manufacturing by 1866 (SMH,21.4.1866).

While the household remained untouched by power technology, it did benefit from some of the developments in heat control. The kitchen range developed separate heat zones for boiling, grilling and baking. The heat from a relatively small fire could be directed to one zone at a time, thus increasing the efficiency of fuel use. This principle was embodied in Flavel's 'Leamington' cast iron range, first exhibited at the 1851 Great Exhibition in London and shown at the Sydney International Exhibition in 1879 (ISN 29.11.1879). Instantaneous temperature control, without physically moving the cooking container to a different heat zone, became possible with the introduction of the gas ring in 1867 (Singer et al 1958, IV,273). By 1877 a wide range of gas stoves, some of them locally manufactured, were available in Sydney, "...varying in size from those which are adapted for cooking a large family dinner down to a size suitable for boiling a kettle or heating a smoothing-iron" (ISN 28.4.1877,23.2.1878). The gas 'geyser' for heating water was patented in Europe in 1865 (Singer et al 1958 IV,273). By

1878 a patented gas bath-heater was manufactured in Sydney, as well as a circulating boiler suitable for attachment to the kitchen range (ISN 26.1.1878).

Refrigeration was one of the most significant developments in energy technology. The fact that food keeps longer at low temperatures has been known since ancient times. Natural ice was used in food preservation even in Sydney: the first shipment of 494 tons of ice from the United States, arrived in January 1855 together with an ice-house and 44 'refrigerators' for sale (Sun 10.1.1911). The supply of ice was intermittent and expensive, and remained a novelty until it could be produced locally. This depended on a reliable form of mechanical refrigeration, a specialized area of energy technology which was largely pioneered in Australia.

The most obvious spur to the development of refrigeration in Australia was the hot climate. The importance of meat in the diet created special difficulties. A contemporary report on ice making commenced with the observation that "...in the summertime it is a common thing for meat to be killed, cooked and eaten the same day..."(SMH 28.9.1875). This was increasingly difficult as the cities expanded, and perishable foods had to be transported further and stored longer before consumption. Urbanisation was therefore another spur to the development of mechanical refrigeration. The third reason was the profit to be made from shipping frozen meat to the European market. By 1870, chilled beef, kept just below freezing by ice-salt mixtures, was being shipped from the US to Britain (Singer et al 1958 V,28). The longer route from Australia required temperatures of -8 C, for which not just ice but low-temperature freezing was necessary.

One of the pioneers of refrigeration in Australia was James Harrison of Geelong. He improved on a 1834 British design for vapour-compression refrigeration and in 1851 installed a prototype machine for a brewery in Bendigo using ether as the refrigerating medium (ibid,47).[15] After 1859 Harrison machines were manufactured commercially in Sydney by the firm of P.N.Russell (Selfe 1896,xxxv).[16] By 1860 a George Street hotel was supplying subscribers with artificial ice at about a sixth of the price previously charged for American imports (SMH 28.12.1860, Sun 3.1.11).

The Sydney businessman T.S.Mort was the first in the world to attempt a systematic integration of refrigeration into both the domestic and export food distribution systems. From 1861 he sponsored work on ammonia-based refrigeration by the Sydney engineer E.D.Nicolle (Selfe 1896,xxxvi). Mort's scheme involved an abattoir in the Lithgow valley with sufficient capacity to fully supply the Sydney and export markets, a freezing plant in Sydney, and cooled rail cars to take the meat direct from the abbatoir to the plant (SMH 4.9.1875). Mort had also considered household regrigeration: he exhibited a prototype domestic ice- maker in Sydney in 1874 (SMH

28.9.75). By 1881 there were two well established central refrigeration works in Sydney and two in the rest of NSW (RC 1881). Home refrigeration, however, still relied on the physical transportation of ice from these works.

Mort's Sydney Fresh Frozen Food and Ice Company plant in Sydney commenced operation in 1875. It supplied ice, chilled beef and milk to the Sydney market, but export remained impossible without a reliable means of keeping the meat frozen en route to Britain. In the event, the first successful consignment of Australian frozen meat was sent not from Sydney but from Queensland, aboard a ship equipped with a Glasgow-designed 'Bell-Coleman' compressed air refrigeration plant. It arrived in London in February 1880 (Linge 1980,454). Mort had backed a technological dead end. The Nicolle freezing process, which required large quantities of heat to evaporate a hydrous ammonia solution, proved difficult to perfect. It was succeeded by more compact machinery on the original Perkins vapour-compression principle which utilised energy in the form of power rather than heat. Further development of commercial refrigeration beyond the confines of the central freezing works and the ice factory waited on the introduction of small, quiet and convenient motors.

Another technology of great significance for electrification was the telegraph, developed in Britain and in the USA in the 1840s, and first commercialised in Britain in 1850 (Singer et al 1958 V,218). It was introduced to Melbourne in 1853 (Moyal 1984,16). [17] Development was rapid in Victoria, and in SA after 1855, but less so in NSW due partly to lack of support from Governor Denison (ibid,21).[18] Nevertheless, the Parkes government authorised the construction of a line from Sydney to Melbourne, and the first stretch, to Liverpool, was opened on 30 December 1857 (ibid,23).

The insulation, switching and other techniques initally developed to shield the rather weak telegraphic signal from the environment were later used to shield the environment from electric power currents: "Much experience gained in the development of the electric telegraph during the period 1840-1880 was turned to good acount when electrical power became generally available" (Singer et al 1958 V,228).

Telegraphy introduced the question of the proper location for cables in cities. Undergrounding was tried in the first SA line from Adelaide to Semaphore, and proved an "endless source of trouble" (Moyal 1984,20). Thereafter almost all telegraph and then telephone lines were installed overhead, and by 1881 the congestion of overhead wires was a serious problem for the economic introduction of electric power cables in Australian cities. The telegraph also led to the rise of a new group of engineers and tradesmen and created a pool of the technical skills necessary for later electrical developments. Together with the railway it introduced engineering issues and rivalries into the sphere of government. Despite the efforts of the Commissioner of Railways to control the telegraph, NSW had a separate Telegraphic Department by 1858 (Moyal 1984,21). This department resisted incorporation into the Post Master General's Department longer than in any other Australian colony, largely due to the efforts of its superintendent, E.C.Cracknell, who after 1881 played an important personal role in the development of the electricity system. The telegraph demonstrated the ability of electricity to carry information, which distiguished it from all other energy forms. In this respect the telegraph was the precursor of all the subsequent applications of electricity to communications and control, a new and valuable category of energy service.

The most significant event in NSW transportation technology in the 40 years to 1881 was the introduction of the railway in 1855. It affected almost every aspect of the colony's economic and administrative development, and acounted for nearly 60% of gross public sector capital formation from 1860 to 1880 (Butlin 1962,348 et seq).[19] The railway represented the first alternative to animal power in land transportation, and so initiated an energy market which has since grown to be the largest single consumer of energy in NSW. The railways also affected the rest of the energy system through their impact on fuel transportation costs. Additionally, the management of such a large and capital-intensive public enterprise led to the acquisition of attitudes and skills which were to influence the subsequent pattern of electrification.

### Energy Demand and Urban Services: More of Everything

Improving material standards of living increased the demand for energy services in the household, in public spaces, in commercial buildings and in industry. In 1841 the energy demands of the various sectors had much in common, apart from the use of power. By 1881, however, each sector had developed its own characteristic energy technologies and patterns of end use.

The population of Sydney increased more than seven-fold between 1841 and 1881. The number of dwellings increased faster than population, giving a steady improvement in both quantity and quality of residential space per person.[20] Innovation in house design and the spread of reticulated services led to increasing specialisation in the function and equipment of rooms. In 1850 only about a quarter of Sydney houses were supplied with water, but by 1881 the central area was well reticulated, with some mains extending as far as Marrickville, St. Peters, Leichhardt and Balmain (Aird 1961,9&12). Apart fom the health benefits of a clean water supply, albeit compromised by the slower development of sewerage, piped water represented a great saving in household labour. It also led to increased hot water demand for bathing and laundry, and equipment for these purposes began to appear. The bathroom, however, was still far from universal. An advertisement for a locally made 'Patent Gas Bath' introduced in 1878 emphasized its portability rather than its suitability for the bathroom: it could "...be fixed by every householder to the gas bracket, in a bedroom, with a hose pipe, and provide a hot bath in a few minutes" (ISN 18.5.1878).

The improvements in house lighting during this period were brought about mostly by oil, since the rate of residential gas connection was modest until the 1870s. Mechanical feed devices developed in the first half of the century much improved oil lamp performance, cheap lamps were being imported in quantity (Cuffley 1973,22), and locally refined kerosene became available in the mid 1860s.

Perhaps the most important stimulus to residential energy demand was the rise in general prosperity and the increasing range of products available for home and personal consumption:

> "The changes in housing standards also made room for increasingly ornate displays of furniture, elementary sanitary fittings and domestic appliances ranging from sewing machines to clothes washing equipment and even household ice-making machines." (Linge 1980,418)

Each of these appliances was widely available Sydney by the late 1870s, as were mincers, grinders, egg-beaters and apple-corers (ISN 28.5.1877). Most were still, of course, worked by hand labour - often the labour of the domestic servants who were always in demand throughout this period (Coghlan 1918, 1281).

The consolidation of Sydney's role as the commercial and administrative centre of NSW was reflected in the physical form of its buildings. Considerable floor areas were required for warehousing, offices and retailing in the City of Sydney at a time when land prices were rising. The resulting increase in building heights created a demand for powered hoists and passenger lifts. The first major woolstore, of five storeys, was built in 1869, and was equipped with a 4 hp steam hoist (Balint et al 1982,23). Several other stores of similar height were built in the 1870s. The first passenger lift in Sydney, imported from the USA, was displayed at the International Exhibition in 1879 (Balint et al 1982,124).

The demand for artificial illumination grew with the construction of bulky commercial buildings, theatres and other places of assembly. The gas lighting which was almost universally installed in these buildings involved open flame combustion, and more light meant more unwanted side effects. There were regular complaints by merchants about the damage done by heat and smoke to merchandise, the danger of fire and the expense of insurance. There was a demand for cool, safe and bright lighting which created a ready market for electricity. For the time being, however, the most effective form of lighting available was gas, and its use increased dramatically as the gas system expanded.

The issue of street lighting set the tone for the relationships between AGL, the municipalities (particularly the City of Sydney) and the government, and laid the ground work for subsequent public debate on electricity. When the SMC took over the administration of Sydney in January 1843 there were 216 outside gas and oil lamps, mainly concentrated in the four central business streets (SMC/LC 14.5.1843).[21] The Lighting Committee of the Council considered AGL's first price too high in comparison with the prevailing charges for street lighting in British cities. It concluded that

> "...it would be cheaper, and more consistent for this Council, to light Sydney with Oil, than to encourage the exorbitance of monopoly by entering into any contract with the Gas Company, on such terms as those stipulated by them..."(ibid).[22]

The directors of AGL pointed out, with some justification, that British gas prices were lower because of higher production volumes, and that they intended to bring prices down when volume increased (SMC/LC 27.3.1843).

The SMC and AGL eventually negotiated the first of a series of contracts in May 1845 (Broomham 1987,36) but the relationship between the organisations remained at best uneasy and frequently hostile.[23] It is probable that AGL's secretary from 1836 to 1879, Ralph Mansfield, wrote the SMH's frequent editorials criticising the Council and praising AGL (ibid,16), and was a key figure in the moves to replace the Council with an appointed Commission (Larcombe 1973 I,105). Nevertheless AGL's relations with the City Commissioners in the three years 1854-56 were equally strained.[24]

Throughout this period AGL's charges for public lighting were lower than its charges to private consumers, giving some weight to its claims to be charging public lighting at cost. However the value of the public lighting load to AGL exceeded the cash return. It represented a firm, long term load of known magnitude which could support the extensions of mains into areas where private demand was not yet developed. AGL generally required evidence of both types of demand before making extensions. The growth rate of the system was constrained on the one hand by AGL's need to maintain a high annual dividend, which would have been more difficult if mains had extended too soon into areas of low load, and on the other by the need to expand fast enough to head off any potential competition.

Another perennial point of issue between the Council and AGL was the repair of the streets after the laying of gas mains. The problems multiplied from the 1850s, as the investment by the Council in street paving increased.[25] Municipal resentment grew as AGL's private business grew, and less of the constant public inconvenience of street openings could be justified as a direct contribution to public amenity. Despite these disputes the standard of public lighting improved steadily, at first in the City and then in the growing suburbs. Table 2.5 indicates the number of inside and outside gas lamps in each year to 1881, as recorded in the AGL directors' minutes. Between 1843 and 1861 the number of persons per lamp in Sydney and suburbs fell from about 180 to 110. It stayed at this level through the 1860s, when lamp installation just matched the high rate of population growth, and improved substantially in the 1870s to 76 persons per lamp in 1881. The light output of each lamp also improved with progressive refinements in design.[26]

The rapid development of industry during this period is described at some length by Linge (1980) and Coghlan (1918). The process of decentralisation begun before 1841 continued, but Sydney remained the focus of production and of technological innovation. The pattern of metropolitan industrial energy use diverged from that in the rest of NSW. Factory mechanisation in Sydney advanced to the stage where almost every process created a demand for power as well as for labour. At the same time the more heat- intensive industries established during the period, such as copper smelting, tended to locate or relocate outside Sydney.

The rate and diversity of mechanisation in Sydney can be gauged from the number of factories with steam engines enumerated in the official Returns of the Colony between 1841 and 1881 (see Table 2.6). In 1841 there were 12 stationary steam engines in all of NSW, and of the 8 in Sydney all but one were used in milling grain. By 1881 there were over 130 powered factories in Sydney. Only 12 of these were flour mills, a further 36 were sawmills, and the rest in a range of industries from baking to printing. By contrast, over 80% of the 445 powered factories outside Sydney were either flour mills or sawmills.

The power plant in Sydney factories tended to be larger than those doing similar work in the rest of NSW. In milling, where the largest engines were used, the average power in Sydney was 43 hp, compared with 17 hp in the rest of NSW (RC 1881). Indeed, such high grinding speeds were being used in Sydney mills that the stones had to be cooled by fans, also driven from the central engine (SMH 12.8.1871). The most heat-intensive factories in Sydney during this period included brickworks, potteries and foundries. An 1870 report on the Goodlet and Smith pottery works in Surry Hills describes extensive forming and pressing machinery:

> "...one of the advantages of the machinery is that from its great power it will be able to work the material much drier than is ordinarily done, thus saving a great deal of the time now required for drying..."(SMH 11.6.1870).

That the saving was seen in terms of time rather than fuel suggests that the greater limitation was the space required to air-dry the products; in effect, the ability to use natural energy in drying processes in Sydney was becoming constrained by the same pressures on urban space which led to the disappearance of wind and water mills. The firing arrangements in the pottery were relatively primitive, with three kilns charged and fired in rotation (ibid). Continuous brick-kiln firing was introduced in the late 1870s (Linge 1980,418).

One of the first metallurgical processing works in Australia, a copper smelter, began operation at Lane Cove in 1849 (Linge 1980,103). The Sydney location had the disadvantage that both fuel and ore had to be transported. The subsequent development of the NSW smelting industries took place either at the ore mines or near the coal mines and by 1881 reached a scale which precluded a location in Sydney. The annual coal consumption of the Hunter River Copper Works, established in 1868 to smelt South Australian ore, was about 24,000 tons (SMH 14.9.1871), or 30 times that of the Lane Cove works. By mid-1872 there were three copper smelters near Newcastle (Linge 1980, 553). Between them they accounted for about 6% of NSW coal consumption, about as much as AGL.[27]

By 1881 industrial energy demand in Sydney called for power rather than heat, and for refinement and control rather than sheer quantity. Many of the local industries were using steam to drive intricate small power operations and as a process heating medium. Probably the first application of gas to industrial heating in Australia took place in 1846, with the establishment of Sydney's first commercial cannery (Farrer 1980,67).

The first railway line in the colony linked Redfern to Granville, a distance of 14 miles, and was officially opened to traffic on 26 September 1855 (Paddison 1956,24).[28] By 1864 there were 143 miles of track operated by steam locomotives, extending from Sydney to Picton in the south, Penrith in the west and Richmond to the northwest (Rae 1866,10). There were still advocates of Governor Denison's view that branch lines would be more economically built on the lighter American pattern and operated by horse power (Linge 1980,393).[29]

The railway had considerable impact on Sydney's suburban growth. In 1856, just after the line to Parramatta was opened, Sydney was still relatively compact, with over three quarters of the population living in the City itself. By 1881, well over half the population was living in the suburbs (RC 1881). Mayne (1981) has argued that the use of the railway for commuting in this period was largely restricted to better paid non-manual workers, because of relatively high fares and the arrangement of timetables. Manual workers tended to live within walking distance of their place of work, and even the introduction of workmen's weekly concessional tickets in May 1881 had only limited influence on the pattern of working class location (ibid,58). As an initially expensive form of transportation, the railways therefore contributed to the differentiation of Sydney's suburban structure by class and income.

The tram was also introduced during this period. It was a more urban transport service than the railway, since all passenger trips were wholly within the metropolitan area. The first horse-powered tramway in Sydney ran along Pitt Street from the rail terminus in Redfern to Circular Quay. It was opened in December 1861 but was taken up in 1866 because of traffic congestion (Paddison 1956,33). Another tramway opened in 1879 to take passengers from the rail terminus to Hunter Street, near the Sydney International Exhibition. After two weeks of horse operation, it was converted to steam (ibid,178). The Tramways Extension Act of 1880 authorized the construction of lines to a number of suburbs, and by 1881 Randwick, Waverley and Woollahra were connected to the City.

In 1881 the NSW government railways and tramways sold roughly the same number of passenger tickets, 6.9 m and 7.1 m respectively (Stat Reg 1892). While the proportion of the rail passengers carried within the metropolitan area is unknown, the trend towards the tramway as the preferred form of powered land transportation in Sydney was already established. While steam proved adequate for the time being, the tramway created a demand for a quieter and cleaner form of motive power better suited to working in dense urban areas: it formed another ready market for electricity.

Steam also came to dominate passenger movement on the harbour. An 1870 parliamentary committee into the control of public vehicles and boats noted that the steam ferries were "fast superseding the old ferry-boats" (NSWV&P/LA, 1870/2,965). The number of steam vessels registered at Sydney rose from 15 in 1841 to 270 in 1881 (see Table 2.6) and an increasing number were operated by the proliferating harbour steam ferry companies, the growth of which is described by Andrews (1975).[30] Despite the growth of steam on land and water, a large part of Sydney's private and public transport services were still provided by horses. The 1870 parliamentary inquiry was told that there were 178 omnibuses, 40 hackney carriages, 180 cabs and 110 drays licensed by the Lord Mayor to ply for hire within the City and within 8 miles of its boundaries (NSWV&P/LA,1870/2,965).

## The Energy Market

All of the energy forms in use in 1841 remained part of the Sydney energy system, and the only new fuel was kerosene. The demand for each form of fuel increased or declined according to developments in mechanisation and energy technology, and its price varies with changes in production, transportation and distribution.

Firewood was still occasionally mentioned as an industrial fuel in the 1840s, but its use soon became restricted to the domestic sector, except in times of high coal prices.[31] Coal was the cheaper form of energy when bought in bulk. The persistence of wood use among householders in the City itself may have reflected their inability to buy and store large quantities of fuel. By 1881 low income dwellings were largely concentrated in the City and inner suburbs, where wood could no longer be gathered free. Urban households were supplied by fuel merchants bringing timber from the outlying districts of Canterbury, St. Georges, Holsworthy and Lane Cove (Greaves 1916,418).[32]

Among wealthier suburban households, wood may have been an aesthetic rather than an economic choice. A description of life in a large Neutral Bay house in the 1870s notes that firewood was brought in by the ketch load from Pittwater, 40 tons at a time: "Although firewood was at hand in abundance, there were no means of getting the same in large enough quantities for household purposes" (Mann 1933,49N1). There was, however, enough wood around Neutral Bay to feed bushfires in the 1860s and 1870s (ibid), so quantities sufficient for small households could presumably still be gathered.

The renewable energy forms which powered Sydney in its early years changed their roles. As the use of horse and wind power in urban mills decreased, their use in primary production in the rest of NSW increased.[33] The horse became the chief source of farm power from the 1820s to the 1930s, for traction and for stationary chaffcutters, winnowers and dairy separators (Birmingham at al 1979,13). Iron and steel windmills to power pumps and other farm machinery were first imported from the USA in the 1870s (ibid,33). In due course wind and horse power were replaced not so much by steam, as was the typical pattern in Sydney, as by the later and more compact technologies of petroleum and electricity. The horse population of NSW increased steadily, to peak in 1910. The ratio of horses per capita in the Sydney energy system actually declined, however: the horse population of the County of Cumberland remained almost static after 1856, while the human population grew rapidly.[34] Davison suggests that the reason was the disappearance of open grazing land near the city, and hence the rising cost of transported feed (Davison 1987,80).

In the industrial energy market, there was both incentive and opportunity to substitutie coal energy for muscle power. The considerable increase in mechanisation from the late 1850s was

> "indicative both of the rise in wages, turning the attention of employers to labour-saving machinery, and of the existence in the colony of the necessary capital to enable business extensions to be carried out" (Coghlan 1918,684).

While bond labour still constituted about 20% of the NSW workforce in 1841, by 1848 practically all workers were free, and the cost of labour varied with market forces (Coghlan

1918,424). The movements in average NSW wage rates calculated by Butlin (1962) are plotted in Fig 2.3. Inflation-adjusted average wage rates increased during the 1860s and 1870s, with sharp fluctuations in the years of gold rushes, and then remained steady for the rest of the century. By contrast, the trend in NSW coal price, also illustrated in Fig 2.3, was downward in the 1860s.

Between 1861 and 1881 the proportion of the NSW workforce employed in factories rose from 3.9% to 10.4%, and about 60% of the factory workforce was located in Sydney (Linge 1980 715,501). Most workers still remained in unmechanised occupations and trades, where powered machinery could neither replace nor increase the productivity of labour.[35] Others used machinery such as sewing machines, which could be powered if concentrated in a factory with a steam engine, but which remained hand powered if used in the home or in small workshops. Even though it still affected a minority of workers, the mechanisation of the factory was a largely irreversible technological change, and it created new markets for energy services in which labour was no longer substitutable for power.[36] Mechanisation introduced processes which could not be carried out at all by hand, however cheap labour became. As a result the sharp increase in coal prices in relation to industrial wage rates in the 1870s, due to a price maintenance agreement between the producers, had no dampening effect on the rate of increase in coal consumption.

Domestic NSW coal consumption remained relatively static in the 1840s and early 1850s, but rose sharply during the post gold-rush years. Between 1841 and 1881 coal production increased 50 fold, and per capita consumption in NSW quadrupled (see Table 2.2). In the 1860s several new mining companies commenced production in the Hunter and Illawarra, and the increased competition initially forced prices down (see Figure 3.3).[37] After several attempts to fix prices the producers, with the support of the miners' unions, managed to maintain a successful cartel throughout the 1870s. The higher prices had little apparent impact on demand. In effect the coal industry managed to divert to itself a greater proportion of the productivity gains of mechanisation.[38] The 'vend' finally collapsed in 1880: by 1881 coal prices had halved, and relatively free market conditions prevailed for the rest of the century.

The Sydney energy system was supplied with coal by a well developed distribution system of merchants. Many of the large industrial consumers, including AGL, took delivery direct at their own wharves on Darling Harbour. The environmental effects of coal combustion became evident during this period: an Act was passed in 1866 in an attempt to mitigate smoke nuisance in the more densely populated parts of the City (Linge 1980,500). While it is impossible to ascertain the details of NSW coal consumption during this period, it is estimated that about a third of it was consumed in Sydney, and over half by railways and steamships on routes which mainly terminated at Sydney.[39]

A litle more than 6% of 1881 NSW coal consumption was for gas making. Between 1863 and 1872 private companies following AGL's lead established new gas works at West Maitland, Newcastle, Mudgee, Goulburn and Bathurst (Keating 1974,70,Wilson 1967,112). In 1875 Sydney acquired its second gas company, the North Shore Gas (NSG) Company, supplying the municipalities of St. Leonard's, East St. Leonard's, Victoria and Willoughby (Keating 1974,77). NSG's production was only a fraction of AGL's, and it did not represent immediate competition, though it served an area which the company may have intended to supply in due course.[40] AGL itself erected gas holders at Haymarket in 1859 and Woolloomooloo in 1860 to serve the spreading reticulation network. The growth of demand in Newtown and Glebe in the following decade required additional plant at Kent St. and additional storage at all sites (Lukey 1897,10). Small outlying works were established at Balmain in 1875 and at Five Dock in 1881.

Tables 2.5 and 2.7 set out the available statistics on the gas sold and lights installed by AGL during this period. Although the records do not distinguish categories of consumers, the relatively slow rise in consumer numbers and the high levels of gas consumption and lights per consumer up to the mid 1860s suggest that gas penetrated the public and commercial lighting markets before the domestic. Both the number of inside lights and the gas consumption per consumer peaked in the late 1860s and began to fall as smaller consumers were added to the system. By the mid 1870s gas had completely penetrated the commercial and street lighting markets in the City, and consumer numbers rose sharply as the rate of dwelling connections increased. In 1881 AGL was on the verge of expansion into the suburbs, again using municipal lighting as the springboard for its load growth. Almost all gas use was for lighting, despite the fact that a wide range of gas heat and power equipment was available by the 1870s. Kitchen ranges, gas engines, bath heaters, irons and industrial burners were all connected but in very small numbers (Broomham 1878,69).

The price of gas declined steadily during this period, with some reversals in times of high coal price. This was due partly to economies of scale and partly to improvements in technology: the gas made from each ton of coal increased 70% from 1841 to 1881. The nominal gas tariff declined from 25s per 1000 cubic feet in 1841 to 7s by 1881. For much of the time, however, the average price realised was lower than the nominal tariff. Early sales were by contract according to the number of lights installed, and revenue was affected by careless or excessive burning by consumers. Meters were progressively introduced during the 1850s and by 1881 only about 10% of gas, probably only the street lighting component, was still sold by contract.

There were frequent complaints by the City Council and in Parliament about the price of gas. AGL paid a 15% dividend to its shareholders in almost every year and its monopoly enabled it to pass on the high coal prices of the 1870s. By the 1860s AGL shares had become one of the colony's safest investments, and were regularly quoted at twice their par value (eg SMH 21.4.1866). The fact that AGL's monopoly was unshakeable may have caused some of the evident resentment against it. There were unsuccessful attempts to set up competing gas companies in 1850, 1863 and 1869 (Broomham 1987,40,65).

AGL was an influential company and well placed to protect its monopoly.[41] Its main commercial interests were to maintain its regular 15% dividend, to secure an equally regular return on more of its shareholders' capital by expanding the business, and to stave off competition. The company had no legal obligation to expand its reticulation area, but failure to do so would have invited competitors. AGL's considerable cash reserves put it in a very strong position to drop prices temporarily to resist competition, but that would have proved not only costly to profits, but as an exercise in pure monopoly power would have used up whatever store of public goodwill remained.

The lighting of middle class homes beyond the reach of the gas system was revolutionised by a new fuel, kerosene. Improvements in oil lamp technology in the first half of the century could not be fully exploited until the introduction of new, cheaper fuels to replace animal and vegetable oils. Kerosene was introduced to Australia within a year of its first production from oil wells in the United States in 1859. Imports from the USA and from Britain grew rapidly in the early 1860s (Cuffley 1973,46). The presence of oil-bearing shales in NSW had been known since 1855, but commercial exploitation of the deposits was not considered until early 1865 (SMH 7.9.1868). The first local production took place in late 1865 at the privately owned Pioneer Kerosene Works near Wollongong (SMH 11.9.1868). The industry then developed rapidly and showed exceptional promise. Four of the six manufacturing companies incorporated by private Acts between 1866 and 1874 were kerosene companies (Linge 1980,795). These had a combined capital of L250,000, fully subscribed by the time the draft Bills were submitted to parliament (ibid,476). Within two years the capital invested exceeded that in the gas industry.[42]

The success of kerosene as a lighting oil was due largely to its price. Selling at 3s per gallon, it was one third the price of sperm oil in 1871 (RC 1871).[43] Whale oil and spermaceti candles also became scarce as the whaling industry declined. The tallow industry developed in the 1840s provided a substitute lighting fuel for local consumption and for export.[44] The statistics for local production, imports and exports yield per capita consumption of purchased, though not self-made, candles in NSW in the 1870s.[45] This remained remarkably steady at about 5lbs per capita through a period of rising domestic gas connections in Sydney and elsewhere, suggesting that candles, which were used mainly by rural and low- income urban households, constituted a separate lighting market from gas and kerosene.

### Sydney and its Energy System in 1881

The patterns of energy demand and of sectional interest which were to shape the introduction of electricity to Sydney over the next two critical decades were clearly established by 1881. The population had increased more than 6 fold since 1851. Over 30% of the NSW population lived in the capital and the proportion was steadily increasing, a trend continued without interruption to the 1970s. The economy was in the middle of a 15 year growth phase, during which "...Australia enjoyed a large measure of prosperity and showed a rapid expansion of industry and commerce..." (Coghlan 1918,1231).

Activities which had previously been mingled were separating into zones through a combination of formal and informal processes. Noxious industries such as slaughtering had been excluded from the city and some rudimentary controls imposed on industrial location and pollution. Residential location was also changing: by 1881 more people lived in the suburbs than in the City itself. Powered land transport in the form of the railway and the tramway contributed to a division by class and occupation. The housing in the City and in the inner industrial suburbs was occupied mainly by lower paid workers who needed to be within walking distance of their employment. The combination of spatial zoning and technological specialisation had by 1881 produced discrete and recognisably modern markets for industrial, commercial, transportation and residential energy services. The various energy forms found niches in these markets according to their characterisitics and relative prices.

Sydney was no longer an economic location for fuel intensive industries, unless they supplied commodities direct to the matropolitan market. The costs of fuel and ore transportation and of urban land were too high. Manufacturing created a large and growing demand for power to operate machinery. Steam had replaced human energy irreversibly in most factories and had made possible the introduction of processes previously beyond the capacity of human strength, speed or skill.

The concentration of commercial activity in Sydney created a new class of energy demand. Higher standards of lighting and other services were needed to make increasingly tall and bulky buildings convenient for their users. The energy for these services was reticulated throughout the buildings via gas pipes or hydraulic lines, just as power was reticulated throughout factories by steam lines, belts or rotating shafts. The entire Sydney commercial district constituted a compact market for energy reticulation. Gas was still the only energy form capable of supplying it: by 1881 gas street lighting was well established in the City and was extending into the new suburban areas. Increasing suburban density allowed the creation of new municipalities to raise rates for local services. Street lighting was usually the first of these, for symbolic as well as practical reasons.

The number of passenger movements by powered means of transport was increasing rapidly. The city was extending along and between the railway lines built in the 1850s and 1860s and the tramway system, like gas, was just beginning to extend into the suburbs. Nevertheless most journeys were still made by foot, and horse- drawn vehicles remained the mainstay of urban goods delivery, of public passenger transport on most routes, and of private transport for the wealthy.

The sector of energy demand which had changed least since 1841 was the residential. Certainly, there had been some improvement in the control of fuel combustion, and the range of fuels available was wider. The quality of domestic lighting was improving with the use of kerosene and gas. Some aspects of housework such as clothes washing were made easier by hand-powered machines, but these innovations were restricted to the wealthy. In most households the rate of change in domestic practice, and hence the demand for energy services, was very slow.

Coal was the dominant fuel in every sector of the Sydney energy system except the residential, where firewood and lighting oils still held much of the market. Coal and coke supplied the heat and power for industry and transport; coal gas supplied most commercial and street lighting energy. It is likely that Sydney's citizens only became aware of their dependence on coal during interruptions in the supply. They may already have perceived the energy system in terms of the companies and technologies associated with the conversion of coal to power, heat and light, rather than with its physical movement or combustion. The point of use was in many cases quite separate, both spatially and temporally, from the point at which the coal was burned or carbonised. The number of consumers who took delivery of coal was declining while the number who consumed its secondary energy products was increasing.

The gas system was undoubtedly the most versatile form of coal energy distribution. By 1881 it was supplying heat, and small amounts of power via the gas engine, although lighting still accounted for the great majority of gas demand. Just as coal was the first primary fuel to penetrate all sectors, gas was the first secondary fuel capable of supplying the entire range of stationary energy services. It was for a brief period the first universal urban fuel. The most modern commercial buildings of the time took all their energy needs from the gas pipe.

The relationship between the gas industry and local goverment set precedents for the political and ideological issues which attended the introduction of electricity. The City of Sydney was the only municipality in NSW until the enactment of the Municipalities Act 1858. By 1881 there were some 35 boroughs and municipal districts in the metropolitan area alone (RC 1881). They were empowered under the 1858 Act to light their streets and to levy rates for the purpose. They had only a single monopoly gas supplier with which to negotiate: AGL or NSG. Complaints of high prices were frequent.

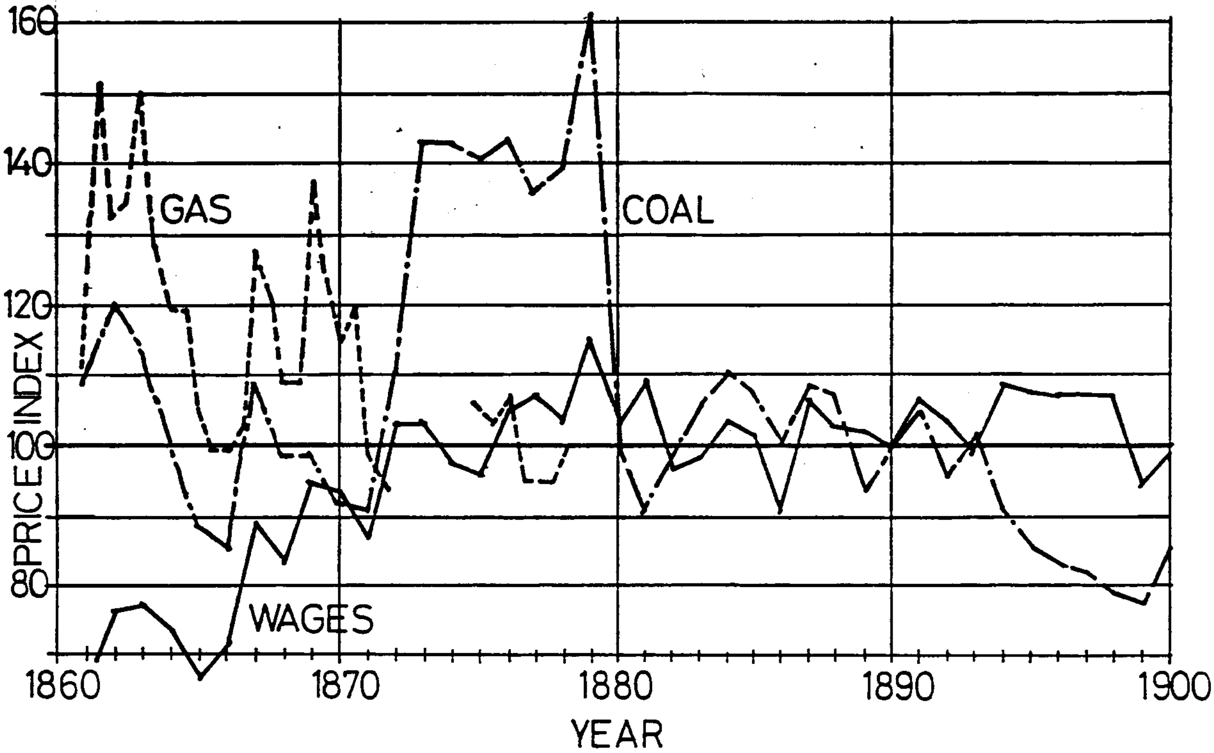
The price of gas was not the only issue. The municipalities, led by Sydney, resented the use of the public streets for private profits. Furthermore, some councillors believed that the provision of services as essential and ubiquitous as gas, even to private consumers, was a legitimate municipal responsibility. Several Sydney municipalities in the 1880s were willing to subsidise public enterprise rather than contract with private companies, even to the extent of establishing their own gas works (Larcombe 1974 II,19).

The control and management of energy distribution in Sydney was of much less major concern to the NSW government in 1881 than it had been to colonial administrations before 1841. The components of the system were managed by private enterprise and were individually small enough, with the exception of AGL, to almost escape government notice. The amount of parliamentary time and interest devoted to energy matters was rising, however. No fewer than four private bills to establish gas companies in country centres were introduced in that year, as well as a bill to extend AGL's powers to own land and to raise capital.

The interests of private energy consumers were also becoming more clearly defined. The price and availability of coal and gas were of increasing importance to their many large industrial and commercial consumers. As energy consumption increased so did the sophistication of consumers in making least-cost choices from the range of available fuels and energy equipment. The energy system was sufficiently complex to involve an ever increasing number of professional engineers in coal mining and transportation, steam boiler and engine design, gas making and reticulation, hydraulic lift design and refrigeration. Engineers were also prominent in the management of technology-intensive public enterprises such as the railways, the telegraph and water supply. As professional advisors to both energy consumers and producers, they played a key role in minimising the material cost of achieving specified tasks.

Despite its growth since 1841, Sydney in 1881 no longer led Australia in population or in urban technology. Melbourne, established in 1835 and created a city in 1847, overtook Sydney in population in the 1850s, and in manufacturing workforce in the 1860s (Coghlan 1918,521,1199). Once Melbourne's first gas company commenced operation in 1856 (Proudley 1987,35) its energy system was as advanced as Sydney's, and it preceded Sydney in the acquisition of the telegraph, the telephone and the electric light. For the last decades of the century, Sydney's rate of electrification was to be dictated by political rather than technological factors.

**FIGURE 2.3**
**TRENDS IN COAL AND GAS PRICES AND AVERAGE WAGE RATES NSW 1860-1900**




(DATA FROM BUTLIN, 1962)

TABLE 2.5
NUMBER OF PUBLIC AND PRIVATE GAS LAMPS
SYDNEY
1843 - 1881

| YEAR | GOVT. | CITY | MUNI-CIPAL | OTHER | SUB-URBANa (a) | TOTAL OUTSIDE LIGHTS | PEOPLE PER OS LIGHT | INSIDE LGHTS | TOTAL LGHTS |
|---|---|---|---|---|---|---|---|---|---|
| 1842 | 25 | 11 | | 140 | | 176 | 191 | 1592 | 1768 |
| 1858 | | | | | | | | | 8205 |
| 1861 | 41 | 443 | 29 | 335 | | 868 | 110 | 10022 | 10890 |
| 1866 | 67 | 685 | 71 | 221 | | 1045 | | 15816 | 16861 |
| 1871 | 76 | 916 | 137 | 142 | 296 | 1273 | 108 | 24463 | 25736 |
| 1876 | 78 | 1004 | 327 | | 439 | 1409 | | | |
| 1881 | | | | | 1390 | 2970 | 76 | | |

Sources: AGL manuscript minutes; incomplete data series
a. From Broomham 1987 Appendix 4.1: probably sum of Municipal and Other outside lights beyond the City boundaries.

**TABLE 2.6**
**MOTIVE POWER IN MILLS, FACTORIES AND SHIPS**
**SYDNEY AND WHOLE OF NSW**
**1841 - 81**

| | 1841 | | 1846 | | 1851(a) | | 1856 | | 1861 | | 1866 | | 1871 | | 1876 | | 1881 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | S | N | S | N | S | N | S | N | S | N | S | N | S | N | S | N | S | N |
| GRAIN MILLS | | | | | | | | | | | | | | | | | | |
| Wind | 7 | 27 | 5 | 28 | 5 | 25 | na | 21 | 4 | 16 | 2 | 10 | 2 | 7 | 1 | 2 | | 1 |
| Water | 2 | 20 | 2 | 30 | 1 | 33 | na | 26 | | 22 | | 13 | | 14 | | 8 | | 9 |
| Horse | | 8 | | 28 | | 25 | na | 15 | | 12 | | 6 | | 9 | | 4 | | 1 |
| Steam | 7 | 27 | 9 | 45 | 12 | 68 | na | 92 | 13 | 134 | 14 | 130 | 14 | 160 | 16 | 150 | 12 | 148 |
| STEAM(b) | | | | | | | | | | | | | | | | | | |
| Bakeries | | | | | | | na | 2 | na | 2 | 2 | 2 | 6 | 6 | 4 | 5 | 5 | 10 |
| Wool Washeries | | | | | | | | | | | | | na | 2 | 2 | 16 | 3 | 17 |
| Woolpresses | | | | | | | | | | | 7 | 14 | 19 | 27 | 17 | 21 | 35 | 43 |
| Sawmills | 1 | 2 | na | na | na | na | na | 19 | na | 61 | 21 | 64 | na | na | 33 | 192 | 36 | 262 |
| Cabinet Works | | | | | | | | | | | | | na | 1 | na | 1 | 1 | 7 |
| Joinery Works | | | | | | | | | | | | | 1 | 1 | 8 | 9 | 18 | 30 |
| Laundries | | | | | | | | | | | 1 | 1 | 2 | 3 | | 3 | 1 | 2 |
| Coffee Mills | | | | | | | | | 2 | 2 | 6 | 8 | na | na | na | na | na | na |
| Stone Dressers | | | | | | | | | | | | | 1 | 1 | 2 | 4 | 1 | 1 |
| Printers | | | | | | | | | | | 4 | 6 | 7 | 9 | 13 | 17 | 15 | 29 |
| - gas(c) | | | | | | | | | | | | | | | 4 | 4 | 4 | 15 |
| Gasworks | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | na | 1 | na | 1 | 6 | 2 | 10 | 4 | 15 |
| Kerosene Works | | | | | | | | | | | 1 | 5 | 3 | 3 | | 2 | 1 | 2 |
| Vessels(d) | 15 | | 23 | | na | | 60 | | 50 | | 97 | 100 | 95 | 98 | 175 | 175 | 270 | 280 |

(Source: Returns of the Colony, Blue Books of Statistics)

a. 1851 Sydney figures are 1859 figures from Walsh (1963).

b. Manufacturing establishments where steam machinery is in use (as motive power in almost every case).

c. Printeries with gas engines installed.

d. Steam boats and ships registered in Sydney and, from 1866, elsewhere in the colony of NSW.

TABLE 2.7
GAS SALES, CONSUMERS AND PER CAPITA CONSUMPTION
AGL
1841 - 81

| YEAR | SALES METER (m cu ft) | SALES CONTRACT (m cu ft) | SALES TOTAL (m cu ft) | CUST-OMERS ('000) | GAS MAKE (a) | SYDNEY POP ('000) | GAS/CUST ('000 cu ft) | GAS/POP ('000 cu ft) |
|---|---|---|---|---|---|---|---|---|
| 1841 | | | 4.0 | 0.06 | 5.94 | 31.62 | 66.7 | 126.5 |
| 1846 | | | 14.4 | | 7.82 | 45.19 | | 318.7 |
| 1851 | | | 21.0 | | 7.76 | 61.11 | | 343.6 |
| 1856 | | | 32.9 | | 8.18 | | | |
| 1861 | 28.8 | 20.0 | 48.8 | 1.37 | 8.60 | 95.79 | 35.6 | 509.4 |
| 1866 | 44.2 | 31.5 | 75.8 | 1.61 | 8.75 | | 47.1 | |
| 1871 | 79.4 | 42.6 | 122.0 | 2.43 | 9.22 | 137.62 | 50.2 | 886.5 |
| 1876 | 173.4 | 26.3 | 199.7 | 5.19 | 9.22 | | 38.5 | |
| 1881 | 341.6 | 50.0 | 391.6 | 11.00 | 10.14 | 224.95 | 35.6 | 1740.9 |

(Source: Gas statistics from AGL manuscript records; Sydney population from RC).

a. Thousand cubic feet of gas made per ton of coal carbonised: exceeds gas sold because of own use and losses in distribution