3. Energy in Australia today

3.1. How energy systems are described

For this study we use the energy balance method of describing Australia's supply and use of energy. This is the internationally accepted method of presenting energy statistics in a standardised format. The energy balance approach is based on a physical understanding of processes for supplying and using energy, but is also consistent with a common sense economic understanding of energy, moving through successive stages of production, supply (or delivery) and use by final consumers.

This representation of the energy system is greatly facilitated by the use of a single common unit for measuring quantities of energy. Australian energy statistics use the petajoule (abbreviation PJ), equal to 10^{15} joules, as the unit. All energy data in this report are expressed in PJ, or smaller multiples such as terajoules (TJ), gigajoules (GJ) of megajoules (MJ). Discussions of electricity alone usually use units of terawatt-hours (TWh), and smaller multiples GWh and MWh. 1 TWh = 3.6 PJ. (See also page viii on Units and Conversion Factors.)

Energy balances start with the extraction or harvesting of what are termed primary fuels; these include fossil fuels such as coal, crude oil and natural gas, which are extracted from the earth, and renewable energy sources such as wind, hydro, biomass and solar thermal energy, which are harvested from the atmosphere, from rivers, from the sea or directly from solar radiation.

Some of these sources of energy can be and are used directly by final consumers, but many of them undergo conversion or transformation to end-use fuels, which are more convenient or efficient for final consumers to use. The most important energy conversion processes are thermal electricity generation and oil refining. Each of these processes uses considerable quantities of energy, so the quantity of end-use fuel produced is significantly less than the quantity of primary energy going into the conversion process. Further quantities of final energy are used or lost in the process of delivering to final consumers. As a result, the total quantity of energy available for use by final consumers is significantly less than the quantity of primary energy supplied to the economy.

The third and last stage of the energy balance representation is final consumption by end users of energy, who use energy for all activities other than the production of energy in another form.

For most forms of renewable energy other than biomass, the distinction between primary and final energy has less practical significance. For example, the total quantity of energy contained in a mass of falling water or moving air is of little practical importance for the energy system unless or until it is converted into final energy, usually in the form of electricity. Therefore the quantity of primary energy produced from these sources is defined by the quantity of hydro or wind electricity which can be produced by generators installed to harvest these renewable resources. Engineering improvements which increase the efficiency with which the energy is captured are expressed as increases in the available hydro or wind resource. Similar considerations apply to direct solar thermal energy. Some of the energy generated is lost in transmission and distribution to the point of final consumption. Therefore, in all these cases, the quantity of final energy is equal to the quantity of primary energy produced less transmission and distribution losses.

Economic descriptions of the energy system usually refer to energy being consumed through these processes. In physical terms, however, energy is not (and cannot be) consumed. Rather, it is converted from a highly concentrated form, notably as the chemical energy contained in fossil fuels, to other forms, such as the chemical energy in an aluminium ingot or the mechanical energy of a rotating pump. Ultimately, most of the energy used by final consumers ends up in the form of low grade heat. The difference between the chemical energy of a fossil fuel and low grade heat is that the former contains far more *useful* energy than low grade heat. (Note that the energy contained in low grade heat has not disappeared, but rather has dispersed into the general environment; it is obvious, for example, in the so-called urban heat island effect, whereby the climate of large cities is typically a few degrees warmer on average than the climate of rural areas surrounding the city.)

The physical concept of useful energy is a key to understanding the potential for improvements in technical energy efficiency. In general terms, efficiency is maximised by maximising the quantity of useful energy which can be obtained from a given quantity of fuel supplied to a process or activity. Most energy efficiency technologies represent ways of applying basic physical principles, such as temperature cascading, to energy using processes, so that extraction of useful energy is increased. The concept of useful energy is also important in understanding many renewable energy technologies. Renewable energy sources occur naturally in a relatively diffuse form, from which it is difficult to extract much useful energy. Most renewable energy technologies aim to extract energy from the environment and deliver it to consumers in a more concentrated form, such as electricity, from which much more useful energy can be extracted.

Electricity obtained from renewable sources, such as hydro and wind, appears in energy balance tables as a form of primary energy, which is supplied directly to final consumers with no intermediate conversion step (but with some proportionate loss in transmission and distribution). The system of energy statistics, which was constructed to suit the centralised, fossil fuel based energy economies of the mid-20th century, has some difficulties in accommodating more extensive use of some forms of decentralised renewable sources of primary energy, because these are often not measured.

Energy statistics have always had difficulty dealing with biomass fuels, such as fuel wood and crop residues, when these are directly collected by final users and do not pass through any market transaction. For this reason, statistics on biomass energy use are subject to a high level of uncertainty. A different sort of uncertainty is associated with figures for the solar contribution to the total energy provided by a solar water heater, which is also not measured, but in this case for reasons of technical practicality, and can only be estimated by indirect methods with a high level of uncertainty. The same usually goes for the electrical energy supplied to a house with a rooftop photovoltaic panel. For yet other ways in which solar energy is used, such as passive solar heating of buildings, it is not even sensible to try to estimate quantities of energy being supplied. It is much better to think of passive solar building design as a type of energy efficiency. Solar water heating and other forms of active solar heating can be similarly thought of as technologies which greatly multiply the useful energy, or, more accurately, the quantity of energy services that can be extracted from a given quantity of energy supplied by conventional (mainly fossil fuel based) energy systems. Of course these measurement difficulties do not arise with renewable energy sources such as wind, which are converted directly to electricity and fed into the supply system, together with electricity generated from fossil fuels.

In this study we have adopted the following conventions for presenting data on energy.

- Passive use of solar energy to heat buildings (and to provide other services, such as clothes drying) is not shown directly, but is expressed as reduced demand for other energy sources to provide the heating and other energy services concerned.
- Active use of solar energy to produce hot water or steam is shown as an energy source, the quantity of which is defined by the amount of alternative (usually fossil) fuel it displaces. This is important to give some idea of the size of the contribution this source of energy can make to meeting Australia's energy demand and of the investment in active solar thermal systems which will be required. The small quantities of electricity used by these generating systems are ignored.
- Renewable energy sources used to generate electricity, such as hydro, wind and direct solar radiation (whether captured by photovoltaic devices or solar thermal electric systems) are defined by the quantity of electricity they supply. Note that this differs from the approach sometimes adopted in international energy statistics, by which renewable sources of electricity are defined in terms of the quantity of fossil fuel they displace, assuming that the fossil fuel is used to produce electricity in a thermal power station with a typical First Law efficiency (33% is normally used).
- Biomass energy sources are defined, like fossil fuel sources, by the quantity of heat energy they release when they undergo complete combustion, i.e. when they are fully oxidised. Note that Australian energy statistics define the calorific value of fuels in terms of their gross calorific value (sometimes termed higher heating value or HHV). This also differs from common international practice, which is to use net calorific value (sometimes termed lower heating value or LHV)[1].
- In calculating the quantities of fossil or biomass fuels required to provide a given quantity of electricity from a thermal power stations, account is taken of the quantities of electricity used within the power station, which for coal fired power stations in particular are quite large, typically about 7% of electricity generated.

There are several ways, apart from the energy balance, of describing or providing important information about a country's energy system. Two of the most valuable are energy use by economic sector and energy use by equipment type.

Energy use by economic sector breaks the economy down into sectors, defined by the standard classification system used for compiling economic statistics, which for Australia is the Australia and New Zealand Standard Industrial Classification (ANZSIC). This presentation can provide far more detail about how and where energy is used in the economy than the energy balance presentation. However,

[1] See the Glossary for definitions of HHV and LHV

ANZSIC does not recognise the distinction between economic activities which are producing primary energy, processing or transforming primary energy, or using final energy. A good deal of "unravelling" is therefore needed to convert the standard energy use by economic sector statistics into the energy balance format.

Energy use by equipment type is very important for assessing the potential for improving the efficiency of energy use, because many of the technical efficiency improvement opportunities are specific to a particular type of equipment.

The Australian Bureau of Agricultural and Resource Economics (ABARE), the Australian Government body which produces Australia's energy statistics, provides data in all the formats described here (and in a number of others). The ABARE energy statistics are the main source of data for the modelling work undertaken for this study. The most recent year for which ABARE has published a complete set of Australian energy statistics is 2000-01. We have therefore used that year as the baseline for this study and for the description of Australia's current pattern of energy use and supply in the next Section of this report.

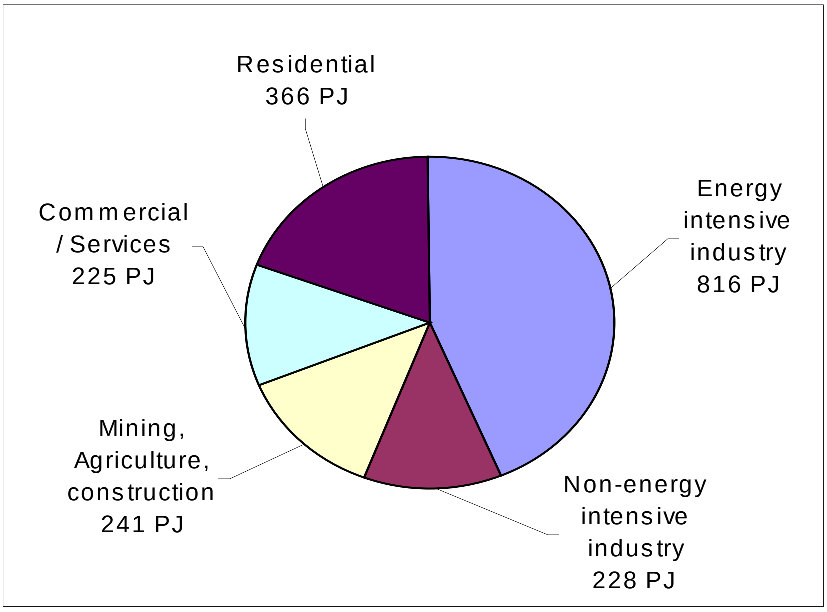
3.2. Australia's current pattern of energy use and supply

In 2001, total stationary final energy use in Australia was 1,888 PJ. This equals about 97 GJ per head of population. By stationary energy use is meant all energy use other than energy used for transport. This figure has been derived from the energy consumption figures published by ABARE by subtracting fossil fuel (mainly petroleum products) used as solvents, lubricants and bitumen. The estimated quantities of fossil fuels (mainly petroleum products and natural gas) used as chemical feedstocks have also been subtracted. Data on feedstock consumption was in some cases provided on a confidential basis by the chemical companies and in other cases has been estimated, using our knowledge of the industries concerned. Our estimate of the total quantity of fossil fuels used for these non-energy purposes in 2001 is about 5 PJ of coal by-products, 87 PJ of petroleum products and 50 PJ of natural gas and ethane, which is about 3.0% of Australia's total fossil fuel consumption in that year (measured in energy units).

For the purposes of this study, we have also defined energy use in fuel production and processing to be final energy use, where the fuel produced is exported rather than being used within Australia. Specifically, energy used for mining export coal and energy use for processing and liquefying natural gas that is exported as LNG have been defined as final energy consumption. Australia has a large export trade in crude oil, but this is more than offset by imports of different (mainly heavier) grades of crude oil. We have therefore not included energy used in producing export crude oil in our estimate of final energy consumption.

Figure 3.1 shows how total final energy use was distributed between the various major groups of economic sectors, and Table 3.1 shows a more detailed breakdown of energy consumption by each economic sector modelled in this study. Note that, since the commercial and residential sector are heavy users of electricity, their shares of final energy are significantly smaller than the shares of primary energy required to supply them, as discussed in later Chapters.

Figure 3.1: Total stationary final energy use by major sectoral group, 2001



In preparing these estimates from the original ABARE data, we have subtracted estimates of fossil fuels used for the various purposes described above, and also the estimated incremental consumption attributable to cogeneration of electricity in various sectors. Although this can only be an estimate, given the integrated nature of cogeneration operation, it is a necessary step for the accurate modelling of a major expansion of cogeneration in our future scenarios.

Table 3.1: Final demand for energy, 2001 (PJ)

Economic sector	Energy consumption (PJ)
Mining (incl. LNG and coal exports)	180
Manufacturing	982
Iron and steel	178
Food, beverages, tobacco	164
Basic chemicals	76
Cement, lime, plaster and concrete	42
All other non-metallic mineral products	49
Non-ferrous metals	339
Wood, paper and printing	70
All other manufacturing	64
Construction	51
Commercial/Services	225
Agriculture/Forestry/Fishing	72
Residential	366
TOTAL final stationary energy consumption	1,876

It can be seen that manufacturing accounted for 52% of the total. We have divided manufacturing into two groups, termed energy intensive and non-energy intensive. Energy intensity, as used here, means energy consumption per dollar of value added from the industry. Examination of the data shows a very clear difference between energy intensive manufacturing sectors and the rest of the economy. The energy intensive sectors of final energy consumption are listed in Table 3.2 below.

Table 3.2: Energy intensive sectors of manufacturing

ANZSIC Subdivision/ Group	Description	Energy intensity 2001 (TJ/$ million value added)
271	Iron and steel	70
252-53	Basic chemicals	34
263	Cement, lime, plaster and concrete	20
261, 262, 264	All other non-metallic mineral products	32
272	Non-ferrous metals	69
23,	Wood and paper product manufacturing	30

These sectors together accounted for 24% of total final energy use (including transport) in 2001 and 40% of total final energy consumption, but only 2.4% of GDP. The average energy intensity of the whole economy in 2001 was 8 TJ per $million. It should be noted that this average includes the energy production and processing industries, such as electricity generation and oil refining, which are also very energy intensive. Transport is also relatively energy intensive. By contrast, the other stationary energy final consumption sectors are far less energy intensive. For example, the intensity of construction is 1.5 TJ/$million value added and the average figure for all service industries is 0.7 TJ/$million value added.

The energy intensive sectors can be further divided into two groups: those which have a predominant or significant export orientation, and those which supply predominantly domestic markets.

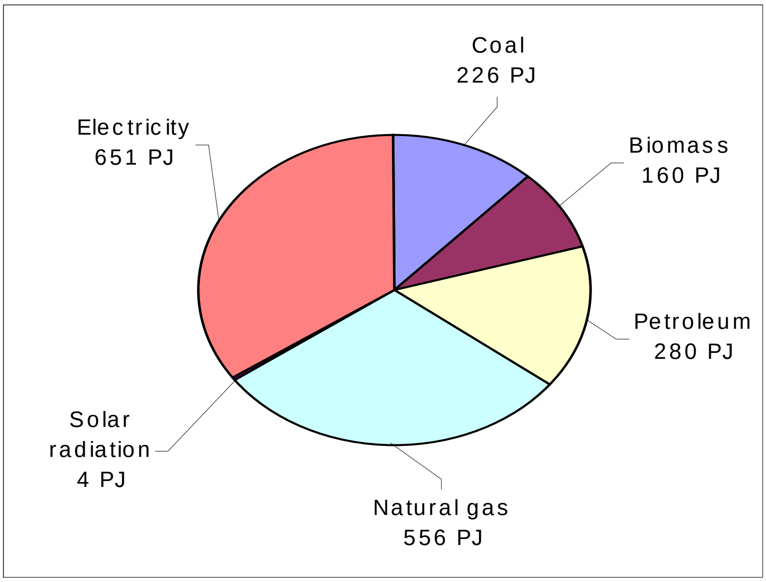
The export focussed groups consist mainly of the non-ferrous metals sector, comprising the production of alumina and aluminium in particular, and also of nickel, copper, zinc, lead and other metals. Production of directly reduced iron (see Chapter 6 for details) is also in this category. While relatively small at present, some analysts expect this to become a major new export industry in the future. Australia also exports significant quantities of steel, but exports have always accounted for less than half of total production. Finally, the production of LNG should be included in this group. However, since there is at present only one LNG producer (the North West Shelf consortium, led by Woodside Petroleum) all relevant economic information about this industry, such as value added, is confidential.

The domestically focussed groups comprise basic chemicals, cement, other non-metallic mineral products, and wood and paper products. At present, none of these sectors has significant exports. There have been sporadic attempts ever since the 1970s to establish some large, export oriented petrochemical manufacturing activities, and several such projects remain under consideration for north west WA. Should one or more such projects be built, the basic chemicals sector would come to resemble the iron and steel sector in having a mix of domestic and export oriented activity.

The energy intensive sectors listed above are all specified and modelled separately in our analysis. The food, beverages and tobacco industry, which is moderately energy intensive, is also modelled as a separate sector. All remaining sectors of manufacturing, which account for the great bulk of value added, but only a small fraction of energy use, are modelled as a single group.

In 2001, a further 1,267 PJ of energy was used in transport. This study is concerned with stationary energy consumption only, so most of the remaining data presented exclude energy used for transport. The mix of the various fuels contributing to total final stationary energy consumption is shown in Figure 3.2.

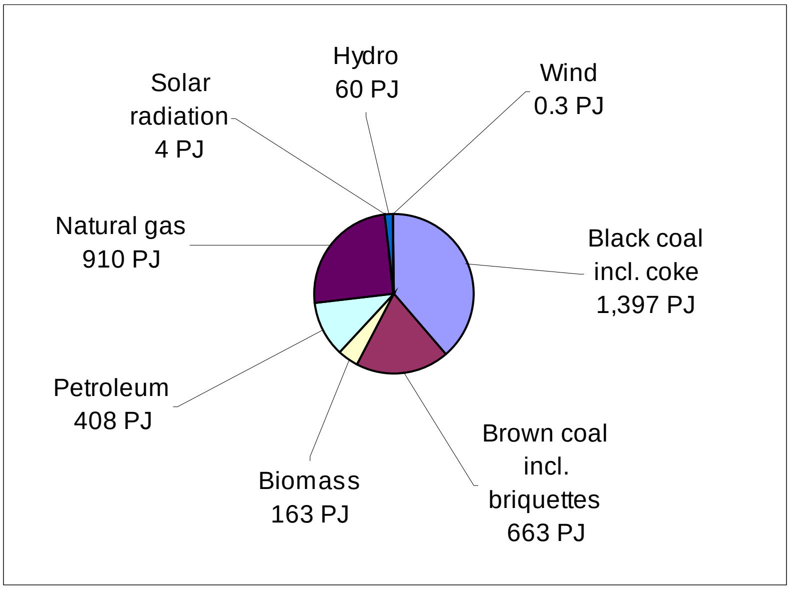
Figure 3.2: Total stationary final energy use by fuel, 2001



It can be seen that electricity and natural gas are the two most important fuels, and relatively small quantities of coal are used in final consumption. When transport is included, petroleum products become the most important fuel used for final energy consumption.

However, as noted in the previous Section, very large quantities of fuel are used to generate electricity and somewhat smaller quantities are used in other energy processing activities, such as oil refining. Total primary energy use in stationary consumption in 2001 was 3,606 PJ. This figure includes all energy use, except final energy consumption of fuels other than electricity for transport, and is equivalent to 186 GJ per head of population. It is this total energy use figure that is the focus of the present study, and the mix of fuels which make up the total is shown in Figure 3.3. It will be noted that it includes energy sources such as hydro and wind that are used directly to produce electricity, following the convention explained in the previous Section. This means that one unit of hydro or wind as primary energy is equivalent to roughly three units of coal or other fossil fuel used for electricity generation. Of the total 3,606 PJ, 2,139 PJ were used in electricity generation and supply, and 229 PJ in other energy processing activities, such as oil refining. It can be seen that coal, most of which is converted to electricity for final use, accounts for well over half of total stationary primary energy consumption. Quantities of petroleum used are relatively modest, as this is predominantly the fuel used for transport.

Figure 3.3: Total stationary primary energy use by fuel, 2001



The modelling of energy demand that we used for this study uses different approaches for final energy demand energy used by the energy supply industries. For the former, the level of economic activity in each sector is exogenously determined, on the basis of projected economic growth, absolute and relative, described in Chapter 4, and anticipated changes in energy intensity of the sector, described in Chapter 5. For the latter, the size of the sector is defined by the quantity of fuel (electricity, petroleum products, coal etc.) which the particular sector produces or processes, and this is determined endogenously by the model. The level of demand for the respective fuels by final energy consumers is the main determinant, but the energy producing and processing sectors themselves also contribute because, for example, some petroleum products are used to generate electricity, and some electricity is used in petroleum refining.

These modelling steps determine the baseline level of demand for each fuel from all stationary combustion sectors. In the subsequent stages of the analysis, enhanced energy efficiency is applied to all sectors. Then active fuel switching towards primary energy sources with inherently lower emissions, such as natural gas, biomass and solar heat, is introduced into the modelling across all sectors.

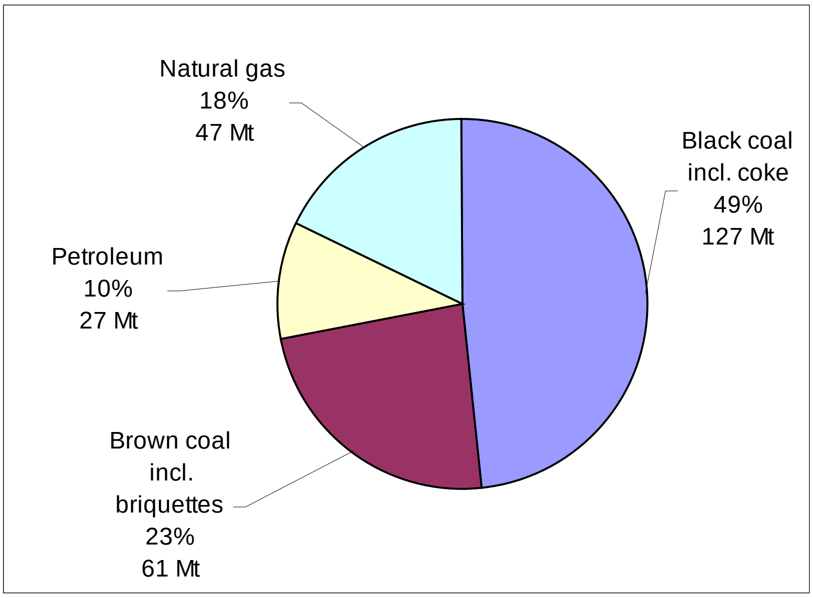
The complete list of energy production and processing sectors used in the model is as follows:

mining of coal for domestic consumption,
production and field processing of oil and gas for domestic consumption,
natural gas transmission and distribution,
electricity generation, transmission and distribution,
petroleum refining,
manufacture of coke,
manufacture of brown coal briquettes.

We assume that the production of brown coal briquettes will cease within a few years.

The primary fuel mix is the most important determinant of the level of greenhouse gas emissions from the energy sector. Anthropogenic emissions of CO_2 from stationary energy combustion in 2001 totalled 262 Mt, which is equivalent to 13.5 tonnes per head of population. The relative contributions to this total of the various primary fuels are shown in Figure 3.4. It can be seen that coal accounts for over 70% of the total emissions. As explained in Section 2.1, in this study we use CO_2 emission as a proxy for total greenhouse gas emissions from combustion of fossil fuels. We also assume that CO_2 emissions from the combustion of biomass fuels do not contribute to anthropogenic greenhouse gas emissions. In this we follow the international greenhouse emission accounting conventions agreed by the IPCC, which specify that if biomass fuels are not produced on a sustainable basis, the resultant CO_2 emissions should be accounted under the category of land use change. Our scenario for 2040 includes a large consumption of biomass fuel and it is of course axiomatic that this fuel be produced sustainably. Chapter 7 describes how this could be achieved.

Figure 3.4: Total stationary energy CO_2 emissions by fuel, 2001

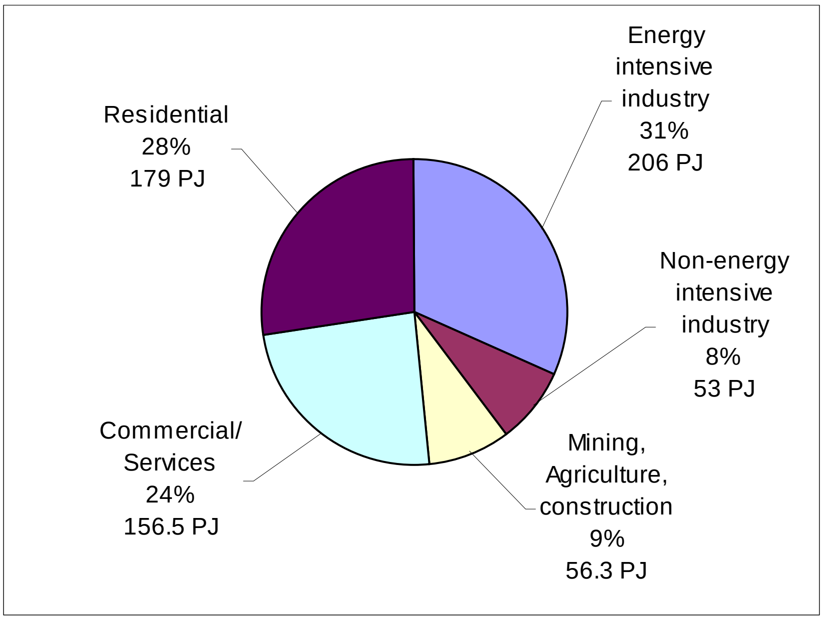


When CO_2 emissions are grouped by sectoral group/activity, it is found that electricity generation accounts for 69% of emissions and all other stationary uses of energy for the remaining 31%. This distribution of emissions of course reflects the fact that most coal is used for electricity generation and most electricity is generated using coal, with over two-thirds of the energy in the coal being lost during generation and delivery. Clearly, if stationary energy emissions are to be halved by 2040, the electricity industry will have to undergo profound changes in the technologies used to generate electricity.

Given the importance of electricity generation, and thus of demand for electricity by final consumers, we conclude this Section with some information about the demand for and the production of electricity.

Figure 3.5 shows demand for electricity by major sectoral group. It can be seen that both the Commercial/Services and the Residential sectors account for much larger shares of demand for electricity than they do of demand for energy in total. This means that measures to limit growth in demand for energy from these sectors, and in particular measures to stimulate greater energy efficiency, will be much more important for limiting greenhouse gas emissions than their shares of final energy consumption might suggest at first glance.

Figure 3.5: Electricity use by major sectoral group, 2001



Figures 3.6 and 3.7 show respectively the mix of fuels used to generate electricity and the CO_2 emissions produced by each of these fuels. The very great importance of coal in both cases can be clearly seen.

Figure 3.6: Primary energy use in electricity generation by fuel, 2001

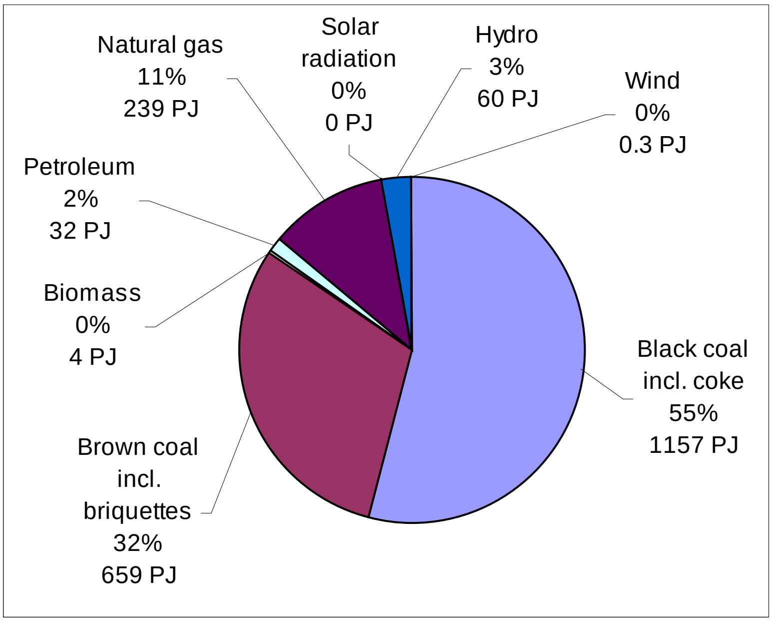


Figure 3.7: CO_2 emissions from electricity generation by fuel, 2001