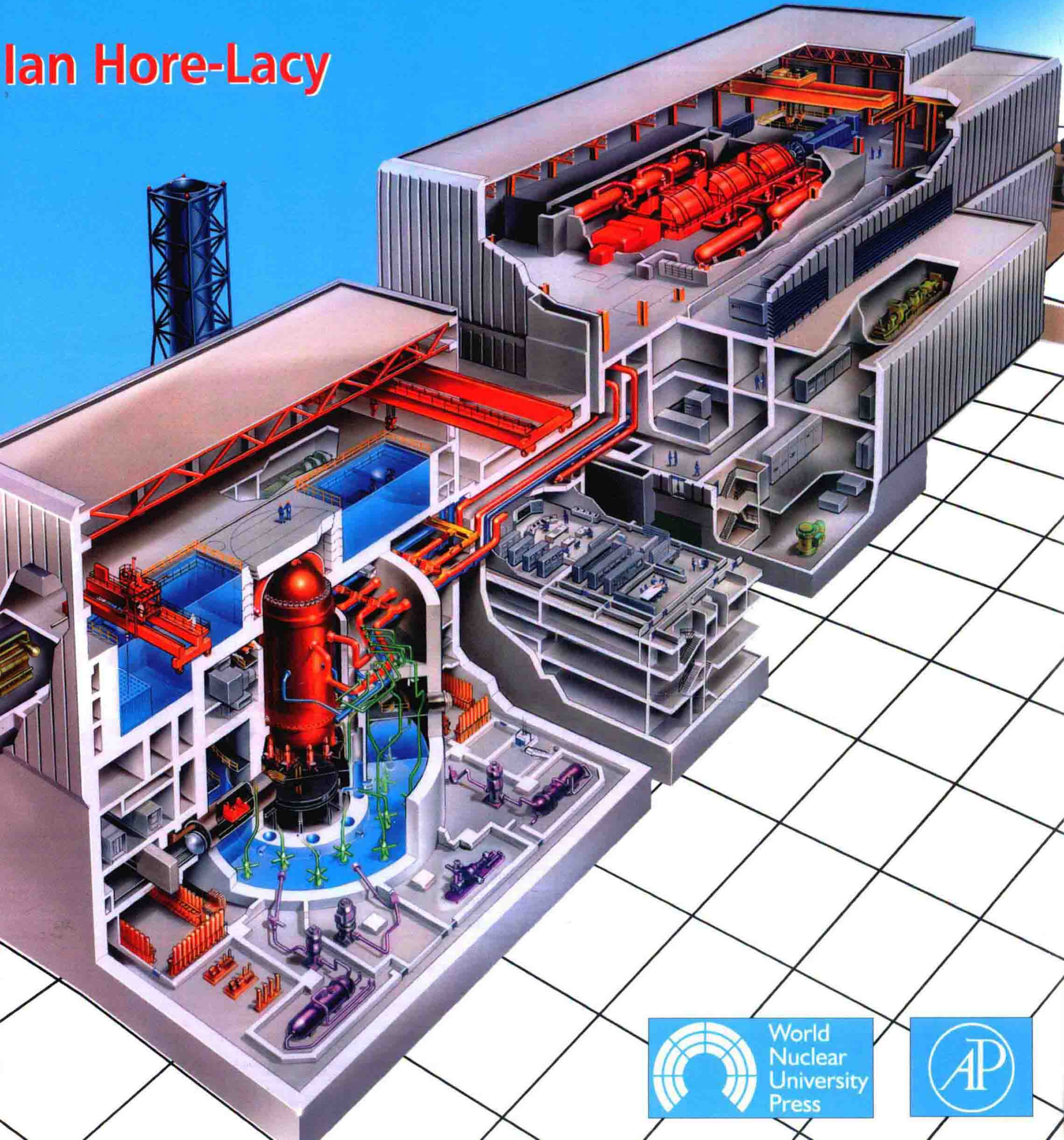
The World Nuclear University Primer

Nuclear Energy in the 21st Century

Ian Hore-Lacy



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Previously published as ***Nuclear Electricity***: 1st - 7th editions, 1978 - 2003

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FOREWORD

by Dr Patrick Moore

Co-founder of Greenpeace, Dr Patrick Moore is Chairman and Chief Scientist of Greenspirit Strategies Ltd in Vancouver, Canada. Website: http://www.greenspiritstrategies.com

Today our foremost energy challenge is to meet increasing needs without adding to our environmental problems, notably global warming and air pollution.

Though there is wide and increasing consensus on the need to severely limit greenhouse gas emissions, a significant reduction seems unlikely, given our continued heavy reliance on fossil fuel consumption. Even UK environmentalist James Lovelock, who posited the Gaia theory that the Earth operates as a giant, self-regulating superorganism, now sees nuclear energy as key to our planet's future health. Lovelock says the first world behaves like an addicted smoker, distracted by short-term benefits and ignorant of long-term risk. "Civilization is in imminent danger," he warns, "and has to use nuclear – the one safe, available energy source – or suffer the pain soon to be inflicted by our outraged planet."

Yet environmental activists, notably Greenpeace and Friends of the Earth, continue to lobby against clean nuclear energy, and in favour of the band-aid Kyoto Treaty plus a string of unrealistic suggestions. We can agree that renewable energies, such as wind, geothermal and hydro are part of the solution. But nuclear energy is the only non-greenhouse gas-emitting power source that can effectively replace fossil fuels and satisfy global demand. The blind and anti-scientific opposition to this proposition goes back to the mid 1980s when Greenpeace and much of the environmental movement made a sharp turn to the political left and began adopting extreme agendas that abandoned science and logic in favour of emotion and sensationalism.

In the last two decades I have pursued the concept of sustainable development and sought to develop an environmental policy platform based on science, logic, and the recognition that more than six billion people need to survive and prosper, every day of the year. Environmental policies that ignore science can actually result in increased risk to human health and ecology. The zero-tolerance policy against nuclear energy that has been adopted by so many activist groups is a perfect example of this outcome. By scaring people into fearing atomic energy, they virtually lock us in to a future of increasing fossil fuel consumption.

That is why I am pleased to commend this book, effectively an eighth edition of a comprehensive introduction to nuclear power, with a scientific basis and pitch. That is where I believe discussion and public debate on the question – and energy policies generally – needs to begin and remain based.

Nuclear energy can play a number of significant roles in improving the quality of our environment while at the same time providing abundant energy for a growing population. First, as mentioned above, it can replace coal and natural gas for electricity production. Coal-fired power plants in the US alone produce nearly 10% of global CO_2 emissions. Under present scenarios, even with aggressive

growth in renewable technologies, coal and natural gas consumption will continue to increase rather than decrease. The only available technology that can reverse this trend is nuclear energy.
France, for example, now obtains over 75% of its electricity from nuclear plants. The other 20% is mostly hydroelectric, therefore making France's electrical production virtually greenhouse gas-free and pollution-free. If other countries had followed France's path, there wouldn't be as much of a climate change issue around power production as there is today.

Second, nuclear energy can be used to produce hydrogen for a future fuel cell-based transportation system. A nuclear plant can produce sufficient heat to split water into hydrogen and oxygen thermally. This is much more efficient than using electricity to split water. There are a lot of technical hurdles and the hydrogen economy may still be years away, but there is no other alternative to using fossil fuels for transportation in the offing. A conversion to hydrogen would not only solve greenhouse gas and pollution concerns, it would have considerable geo-political implications regarding energy security.

Third, nuclear energy can be used to desalinate seawater to provide water for drinking, industry and irrigation. A growing population, shrinking aquifers and increasing irrigation demand all add up to the need to make our own fresh water in the future. Nuclear can provide the energy to do it without causing pollution or greenhouse gas emissions.

Fourth, we will continue to use fossil fuels, hopefully at reduced levels, far into the future. As conventional supplies of oil diminish we will turn to the vast shale oil and oil sand deposits. This is already a growing industry in northern Canada where the oil sands contain as much proven supply as Saudi Arabia. But the oil costs more because it must be separated from the sand. This is done by burning large volumes of natural gas to make steam, then basically steam-cleaning the sand to get the oil. By using one fossil fuel to obtain another there are even more greenhouse gas emissions than from burning conventional oil supplies. One solution to this would be to use nuclear energy to make the steam, and electricity, to run these oil sand and shale oil projects. This would substantially reduce greenhouse gas emissions and air pollution.

There are about 440 nuclear power reactors operating in 30 countries, producing 16% of the world's electricity. This could be doubled or tripled if the political will were brought to bear on the issue of reducing fossil fuel consumption. I believe that the environment would benefit from moving in this direction. Let's hope the future takes us there.

ABOUT THE AUTHOR

Ian Hore-Lacy, MSc FACE, a former biology teacher, became General Manager of the Uranium Information Centre, Melbourne, in 1995 and Head of Communications for the World Nuclear Association, based in London, in 2001.

He joined the mining industry as an environmental scientist in 1974, where his responsibilities covered uranium production. From 1988-1993 he was Manager, Education and Environment, with CRA Limited (now Rio Tinto). Since 1976, he has written and published several books on environmental and mining topics, including *Responsible Dominion – a Christian Approach to Sustainable Development* (Regent College Publishing 2006). He is a contributor to Elsevier's *Dictionary of Energy* and *Encyclopedia of Energy* (both 2005). His particular interests range from the technical to the ethical and theological aspects of mineral resources, including their use in applications such as nuclear power. He has four adult children.

Early editions of this book owed their substance to Ron Hubery as co-author. Ron is a chemical engineer, now retired, who spent eight years working with the Australian Atomic Energy Commission (now the Australian Nuclear Science and Technology Organisation) on nuclear fuel cycles and reprocessing. He also worked at the uranium production centres of Rum Jungle and Mary Kathleen in Australia.

ACKNOWLEDGMENTS

This text builds on seven editions of *Nuclear Electricity*, 1978-2003, published (since 4th edition) by the Uranium Information Centre (UIC) in Melbourne, assisted at various stages by Atomic Energy of Canada Ltd and the World Nuclear Association. Without that basis and my colleagues at WNA since 2001, this book would have been a formidable and possibly futile undertaking.

Section 3.7 on Physics draws heavily on material written for UIC by Dr Alan Marks. Chapter 9 draws heavily on the introductory section of *Atomic Rise and Fall, the Australian Atomic Energy Commission 1953-1987*, by Clarence Hardy, Glen Haven, 1999; and the Russian part of it was largely contributed by Judith Perera. In all cases material is used with permission.

The front cover image was supplied by General Electric Co. and shows an Advanced Boiling Water Reactor (ABWR).

This book was designed by Brigita Praznik, Graphic Information Designer at the World Nuclear Association. Figures in this edition were by Sara Pavan.

INTRODUCTION

The context

There is a rapidly-increasing world demand for energy, and especially for electricity. Much of the electricity demand is for continuous, reliable supply on a large scale, which generally only fossil fuels and nuclear power can meet.

The fuel for nuclear power to make electricity is uranium, and uranium's only substantial non-weapons use is to power nuclear reactors. There are some 900 nuclear reactors operating today around the world. These include:

- about 260 small reactors, used for research and for producing isotopes for medicine and industry in 56 countries,
- over 220 small reactors powering about 150 ships, mostly submarines,
- some 440 larger reactors generating electricity in 30 countries.

Practically all of the uranium produced today goes into electricity production with a significant small proportion used for producing radioisotopes. In particular, uranium is generally used for base-load electricity. Here it competes with coal, and in recent years, natural gas.

Over the last 50 years nuclear energy has become a major source of the world's electricity. It now provides 16% of the world's total. It has the potential to contribute much more, especially if greenhouse concerns lead to a change in the relative economic advantage of nuclear electricity, emphasizing its ethical desirability. On top of that there is an emerging prospect of the Hydrogen Economy, with much transport eventually running on hydrogen. Just as nuclear power now produces electricity as an energy carrier, it is likely to produce much of the hydrogen, another energy carrier.

The uranium and nuclear power debate today is about options for producing electricity. None of those options are without some risk or side effects.

Since the first edition of this book's predecessor in 1978 – *Nuclear Electricity* – many of the expectations surrounding alternative energy sources have been shown to be unrealistic (as indeed have some of those for nuclear energy). However, it is important that this return to reality does not lead to their neglect; such alternatives should continue to be developed, and applied where they are appropriate. In particular a great deal can be achieved by matching the location, scale and thermodynamic character of energy sources to particular energy needs. Such action should be a higher priority than merely expanding capacity to supply high-grade electrical energy where for example only low-grade heat is required, or using versatile gas to generate electricity on a large scale simply because the plant is cheaply and quickly built.

But when the question of utilizing nuclear energy arises, there are those who wish somehow to put the genie back in the bottle and to return to some pre-nuclear innocence. The debate in Europe is instructive: France gets over 75% of its electricity from nuclear power. It is the world's largest electricity exporter, and gains some EUR 2.5 billion per year from those exports. Next door is Italy, a major industrial country without any operating nuclear power plants. It is the world's largest net importer of electricity, and most of that comes ultimately from France. Elsewhere Germany and Sweden have nuclear phase out policies which are patently unrealistic.

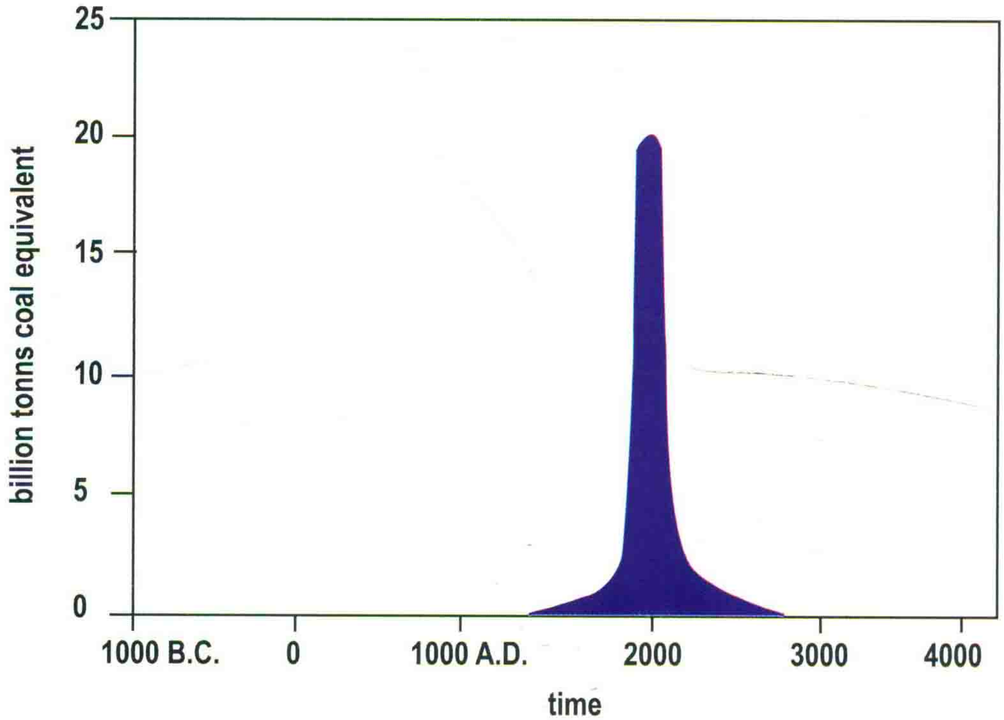
The present and future roles of nuclear power are not limited to electricity, and hence the expanded scope of this book beyond *Nuclear Electricity*. The large potential for nuclear heat to make hydrogen to fuel motor vehicles is perhaps the chief interest today, but nuclear energy for desalination (as potable water becomes a more valuable commodity), marine propulsion, space exploration, and research reactors to make radioisotopes are all encompassed in this book.

I anticipate that my grandchildren's generation will come to look upon weapons as simply an initial aberration of the nuclear age, rather than a major characteristic of it. Arguably the same is true of the bronze and iron ages, where weapons provided incentive for technological development which then became applied very widely.

Certainly, as Figure I graphically shows, we cannot indefinitely depend on fossil fuels as fully as we do today.

Figure 1: Consumption of fossil fuels

Source: Charles McCombie, NAGRA Bulletin # 29, 1997, based on Korff, 1992 (and probably M.K. Hubbert, 1969, who had the peak around 2100).



The book

Considerable effort has been made to include as much up-to-date and pertinent information as possible on generating electricity from nuclear energy, and on other uses of nuclear power. The figures quoted are conservative, and generalizations are intended to withstand rigorous scrutiny. The reader will not see many of the frequently repeated assertions from supporters or opponents of nuclear energy. The book does not enter into debate on social issues.

Since the first edition of *Nuclear Electricity*, the intention has been to get behind the controversies and selective arguments and present facts about energy demand and how it is met, in part, by nuclear power. Every form of energy production and conversion effects the environment and carries risks. Nuclear energy has its challenges, but these are frequently misunderstood and often misrepresented. Nuclear energy remains a safe, reliable, clean, and generally economic source of electricity. But many people do not see it that way.

This edition comes out at a time when the contrast between environmental concern focused on tangible indicators of pollution and global warming is beginning to stand in stark contrast to Romantic environmentalism, which is driven by mistrust of science and technology, and which demonizes nuclear power. Increasing evidence of the contribution to global warming from burning fossil fuels is countered by fearmongering often based on the 1986 Chernobyl disaster.

The introduction to the first edition of this book in the 1970s expressed the opinion that if more effort were put into improving the safety and effectiveness of commercial nuclear power, and correspondingly less into ideological battles with those who wished it had never been invented, then the world would be much better off. With Chernobyl nearly two decades behind us and the great improvements to safety in those plants which most needed it, plus the welcome recycling of military uranium into making electricity, it seems that we are now closer to that state of affairs.

Further information

Throughout the text, there are references to World Nuclear Association (WNA) Information Papers, which cover some of the issues found in the book in more detail. These papers can be read by visiting the WNA website at: http://www.world-nuclear.org. This site also offers up-to-date news, articles and reports on nuclear energy issues, as well as links to other sites with reliable information.

1 ENERGY USE

1.1 SOURCES OF ENERGY

All energy is derived ultimately from the elemental matter which comprises both the Sun and the Earth, formed in supernovae over 6 billion years ago. From the Sun we have both fossil fuels and the main contemporary renewable sources. From the elemental substance of the Earth we have uranium and geological heat.

The Sun warms our planet, and provides the light required for plants to grow. In past geological ages the Sun provided the same kind of energy inputs. Its energy was incorporated into the particular plant and animal life (biomass) from which were derived today's coal, oil and natural gas deposits – the all-important fossil fuels on which our civilization depends.

The only other ultimate energy source in the Earth is from the atoms of particular elements formed before the solar system itself. These are found today in the Earth's crust[1] and mantle.

The amount of energy per unit mass of an atom is dependent on the size of the atom: the minimum amount of energy per unit mass is contained within the medium-sized atoms (such as carbon and oxygen), whereas the greatest amount is contained in small atoms (such as hydrogen) or large atoms (such as uranium). Energy can therefore be released by combining small atoms to produce larger ones (fusion) or by splitting large atoms to produce medium sized atoms (fission). The tapping of this energy by nuclear fission or by nuclear fusion is one of the most important and contentious human achievements in history.

1.2 SUSTAINABILITY OF ENERGY

Much has been written since the early 1970s about the impending "world energy crisis", which was initially perceived as a crisis due to limited oil supplies. Today it is more a geopolitical crisis due to the location of supplies of oil and gas resources relative to demand for them. But finite supplies are still a factor, and Figure 1 (see Introduction) suggests the vital importance of conserving fossil fuel resources for future generations and the importance of sustainability.

Since the early 1970s the pressure has been to conserve crude oil supplies, but in the future it will increasingly be to reduce burning of all fossil fuels. Today global warming concerns drive this trend strongly. It is likely that coal will take over some of the roles of oil today, especially as a chemical feedstock. Sustainability of energy relates both to adequacy of supplies and the environmental effects of its use.

The importance of energy conservation is obvious, even in areas where so far fuels have been relatively cheap, and the need to limit carbon emissions lends emphasis to this. The levelling-out of overall energy demand in developed countries in recent decades is a result of increased energy efficiency. However, in developing countries growth in energy demand from a low starting point continually increases the pressures on resources worldwide, despite conservation initiatives (see Table 1).

Many people in developing nations aspire to the standard of living, mobility, agricultural productivity and industrialization characteristic of the developed countries. Fulfilling these hopes depends on the availability of abundant energy. Growth of the world's population from the present level of 6 billion people to a projected 8 billion in 2025, mostly in today's developing nations, increases the challenge.

[1] Uranium appears to have been formed in supernovae some 6.5 billion years ago, and though not common in the solar system has been concentrated in the Earth's crust at an average of c. 1.4 ppm. Heat from the radioactive decay of this uranium today drives the convection processes in the Earth's mantle and is vital to life.

Table 1: Growing electricity production – terawatt hours (TWh, or billion kWh)

	1990	2003	increase
OECD	7603	9938	31%
Non-OECD	4270	6307	148%
World	11873	16742	41%
Non-OECD:			
Former USSR	1727	1349	minus 22%
Africa	323	507	57%
Latin America	491	829	69%
Asia (exc China)	647	1433	121%
China	650	1943	199%
Middle East	236	553	134%

Source: OECD[2]/International Energy Agency (IEA) 2005, Energy Statistics of Non-OECD Countries, 2002-2003.
See also Figures 2 & 5.

1.3 ENERGY DEMAND

In industrialized countries energy demand derives from three major sectors:

- Domestic and commercial
- Industry and agriculture
- Transport

In many countries these each account for about one third of the energy demand, although the size of domestic demand depends very much on climate. In Australia, for example, domestic demand is relatively small, whereas in Canada it is extremely large because of the cold climate.

More specifically it is possible to identify demand for particular purposes within these sectors, such as the following:

- Low temperature heat (up to 110°C) for water and space heating in homes and industry
- High temperature heat (over 110°C) for industrial processes
- Lighting
- Motive power for factories, appliances and some public transport
- Mobile transport for public and private use

For some of these purposes there is a significant demand for energy in the form of electricity. Worldwide, electricity demand is increasing very rapidly, as illustrated in Table 1 and Figure 3. This is discussed further in section 2.1.

1.4 ENERGY SUPPLY

On the supply side, there are a number of primary energy sources available (see Figure 2). Derived from these primary sources are several secondary energy sources or carriers. These include, for example:

- Electricity – can be generated from many primary sources
- Hydrogen – mainly from natural gas or electrolysis of water
- Alcohols – from wood and other plant material
- Oil and gas – manufactured from coal

At this stage only electricity is of major importance as a secondary source, but hydrogen is expected to become significant in the future as a replacement for oil products. (see Chapter 6).

[2] Organization for Economic Cooperation and Development