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PART ONE

Introduction and background

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CHAPTER 1

Introduction: the issue of energy

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An energetic world

Energy is the basic currency of the biosphere. Without energy, *change* is impossible. Without energy, matter cannot be moved or transformed; quite simply, nothing can be done. Picture an animal or group of animals chasing prey in a natural ecosystem. Should these animals expend more energy than they eventually gain through eating the food they find, they will surely die.

For the vast bulk of the history of life on Earth, over many hundreds of millions of years, this was an unbending law for all living things. An organism survived on that fraction of the energy flowing through its environment that it could capture and use within its own body. In the relatively very recent past, however, one species of animal, *Homo sapiens*, has managed to escape the constraints of this law. When humans first began using fire, they developed an attribute that was to change the course of planetary history – the ability to tap sources of energy external to their own bodies. And so our species started being different from other animals, doing unique things like creating heat, cooking food, and changing the landscape through burning.

Before the use of fire, our ancestors had available to them only that energy that flowed through their own bodies, taken in as food and expended through metabolic processes just like any other animal (this can be called *somatic energy*). An average figure for somatic energy for an adult human being is about 10 megajoules (MJ) per day or 3.65 gigajoules (GJ) per year (this figure varies with body weight, activity level, climate, and so on). The use of fire in hunter–gatherer societies provided an additional source of energy – *extrasomatic energy* – which

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probably about doubled the energy budget of a human being to 7 or 8 GJ per year (Boyden 1987). The domestication of certain animal species and their subsequent use as a source of draught power was a later and highly significant development.

When we consider the history of technological development, we tend to think of *devices* such as wheels, internal combustion engines and telecommunication equipment. But the underlying basis of technological and economic development has been the introduction of new sources of usable energy. It has been said that '... from one perspective, history is the story of the control over energy sources for the benefit of society' (Goldemberg *et al.* 1988: 2). Ponting (1992) supports this view, describing the use of fossil fuels as the second great transition in human history, after the advent of farming. Since the discovery of fire, humans have added much more potent sources of energy to their repertoire – coal, oil, uranium, various gases, the power of moving wind and water. These have been the ways around the basic energy constraint of life. The increase in the use of energy by humans has quite literally been explosive. The global average use of energy is now about 70 GJ per year, and as high as 400 GJ in some countries.

This book is based on the view that the supply and use of energy by humankind is a crucial problem that must be confronted if we are to achieve an ecologically sustainable and humanly desirable future. Using energy has allowed us to do things that have both enabled and enriched the lives of countless millions of people – cooking food, growing more food, keeping warmer or cooler in harsh climates, building homes, communicating, making machines and other objects, providing transport and other services – all such things require energy. But this has not been without cost.

The issue of energy is of overwhelming importance for five basic reasons:

1. Because it is required to move or transform matter, energy reflects the *level of physical activity* (i.e. the scale of interaction with the surrounding environment) of any defined entity, be it an individual, a firm, a region, a society, or the global human population.
2. Because of this, energy is a necessary and irreplaceable input of *all* sectors in a modern economy; the flow of energy through a production system may be reduced relative to unit output, but never eliminated. Energy is one of the few categories of resources that are common to all human activities (the only others arguably being land and labour) – *everything* consumed or used by humans has an energy component.
3. The waste products of the fossil-fuel-based energy systems of

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industrialised countries are the primary cause of predicted global environmental change resulting from the enhanced greenhouse effect (particularly emissions of carbon dioxide).

4. These same energy systems are also the source of the bulk of the troublesome air pollutants in industrial societies (oxides of carbon, sulfur and nitrogen).
5. The bulk of energy used is from non-renewable sources such as coal, oil, natural gas or uranium. Very little commercial energy is from renewable sources. The eventual exhaustion of these resource stocks is therefore inevitable and a cause for concern.

These points need to be kept in mind lest we slip into treating energy as just another commodity. Energy is a pervasive challenge in questions of sustainability (Peet 1992 offers an excellent and detailed discussion).

In discussing a society's impact on the environment, the equation of Wasi (1991) captures the essence of the problem:

$$E = NB$$

where E is environmental impact, N is the number of people, and B is their behaviour. *Behaviour* is complex, and the hardest variable to define, being the totality of actions of an individual or group of people. Behaviour is shaped by a variety of cultural, political, technological and economic factors. In terms of impact on the environment, behaviour can be related to the consumption of natural resources and the use of the assimilative capacity of the environment to absorb wastes. In terms of energy use, this is important as it recognises a fundamental point: a country small in population (like Australia) can have a disproportionately large impact, per person, on the global environment due to its very high per capita rate of consumption.

It can be argued that energy use, per capita or total, is a useful single indicator of the 'environmental load' of a person or a society (although, of course, it is not the only indicator). Since the time that people first started farming some twelve thousand years ago, the figures for total energy use would indicate that *the environmental load that humans place on the biosphere has increased more than ten-thousand-fold.* It is still rising in line with increases in both per capita energy use and population. The World Commission on Environment and Development (the 'Brundtland' commission) noted that, given existing technologies, bringing the whole world's resource and energy consumption up to that which the industrialised countries now enjoy would increase total energy consumption five-fold. The Commission was of the opinion that the biosphere could not tolerate the implications of this (WCED 1987).

So we face the challenge of whether human society can create systems of energy supply and use which are ecologically sustainable in the long term and can allow us to satisfy the requirements for the health and well-being of all people. Further energy-intensive development has become the traditional way of meeting our needs. Given that human society is currently *not* ecologically sustainable, and that the health and well-being needs of all people are most certainly not being met, the challenge is clearly one of great magnitude (see, for example, WCED 1987).

The various chapters in this book seek first to make clear why the issue of energy is so important, and then to point towards some directions that might be taken in accepting this challenge.

The five points above can provide an initial basis upon which to assess energy systems and energy futures. In terms of the first point, a reduction in the total human energy load would appear desirable. Point 2 focuses attention on increasing the effectiveness of using energy to produce a given commodity or service. Points 3–5 emphasise the need for energy systems which minimise the production of wastes and maximise the renewability of the energy resources relied upon.

To embark on a positive note, there is a fundamental truth that should be a touchstone in this search for direction. It may seem contrary to the importance placed here on energy, but in fact *no one really wants energy* (Patterson 1991). What we want, at the risk of speaking in platitudes, is health and happiness. We humans want the things that make life comfortable and rewarding, and energy is necessary for any of this – to eat, to keep sheltered, to travel to see friends and relatives, to recreate, and so on. Energy is but a means to these ends. The question is, can we achieve these ends with less of the means?

The nature of energy

Energy is a common word, used to mean many things in a multitude of contexts. We need to define early on the sense in which the word energy, and related terms, are used in this book (for more detail, see Odum and Odum 1976; Slesser 1982; Patterson 1991).

The word 'energy' comes from the Greek *ergon* (work) and *en* (in), and was proposed in the early nineteenth century by Thomas Young as, essentially, a term to describe the *ability to do work*. This, and related developments, represented a significant event in our ability to understand the physical world. The standard unit for measuring energy is the *joule* (J) or multiples thereof (other units are also used – see conversion table). All matter has an energy content, which can be quantified as its energy density at certain conditions and varies greatly (for example: oil, 42 MJ/kg; liquid hydrogen, 120 MJ/kg; straw, 18 MJ/kg). Energy takes many forms, including, for example, the *kinetic* energy of a body in motion, the *chemical* energy released in metabolising food, or the

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potential energy inherent in an object poised to fall or a chemical that may react.

Related concepts are work and power. *Work* is a measure of effort, and is also typically measured in joules. *Power* is the rate at which work is done and is measured in *watts* (W) or multiples thereof. A watt is equivalent to one joule per second. Thus power can be thought of as the *rate* at which energy is being converted. *Heat* is energy in transfer from one environment or system to another.

There are two basic laws that, as far as we are aware, represent absolute constraints that are crucial for understanding energy. Simply stated, these are:

- **The first law of thermodynamics** (alternatively the law of the conservation of energy), which states that energy can be converted into another form, or conserved for a length of time in one form – *but energy can never be created or destroyed.* Energy flowing into a system is either stored there or flows out. Thus the total amount of energy, in all its forms combined, remains constant.

  (This law forces us to accept that, although we always talk about energy 'consumption', energy is never actually consumed, but rather used. We simply transfer it from one form to another in processes that have, usually, some desired outcome.)
- **The second law of thermodynamics** (alternatively the law of the degradation of energy), which states that, in any process, some of the energy will be dissipated or degraded. This law is sometimes stated as meaning that any system tends towards increasing disorder, and is sometimes also called the *entropy* law.

  The best illustration of this law is the fact that no conversion of energy can be perfect – energy is 'lost' to the system, becoming lower quality energy that cannot be used by the system. Such a system might be an organism (about 90% of the energy in food is typically dissipated as waste heat); a car (only around a tenth of the energy in the fuel (petrol or gasoline) moves the car along, the rest is lost as waste heat, chemical energy in emissions, and friction); or a thermal electricity generation plant, where perhaps 10 J of energy in coal is combusted to produce 3 J of electricity. This 'loss' of energy to a system is tolerable, as long as the incoming energy supply is maintained, because some of the energy is converted into a more organised state, a higher quality, which the system desires. An organism 'wastes' energy as heat, but stores some as body tissue or uses some in metabolic processes, and thus maintains itself. A generation plant disperses most of the coal's energy content, but converts some into the incredibly useful and high quality form of electricity.

Critical to the issue of energy are its various sources. The biosphere is powered by solar energy from the Sun: it gains energy from the Sun and this is balanced by the eventual loss of energy back to space. A minute fraction of the Sun's energy reaches Earth and more than half of that is either reflected before reaching the surface, or is absorbed by the atmosphere. Of that reaching the Earth's surface, about 30% is reflected as heat, 21% drives the winds and about 40% is involved in the evaporation and condensation of water. Less than 1% is captured by plants and converted into chemical energy via *photosynthesis*, the process which underpins the existence of life as we know it.

Both natural ecosystems and human-managed ecosystems thus run on solar energy. Different ecosystems vary widely in the amount of energy that flows through them, and this is a measure of their biological productivity. Table 1.1 gives some examples of the extreme 'patchiness' of production in the natural world: its energy intensity. The variability of energy intensity in a human society is discussed in the next chapter.

Humans, like all other animals, 'eat' solar energy in the form of either plant or animal tissue, taking in both energy and nutrients. When humans first deliberately used fire, they were of course using solar energy, but it was energy that had been stored for a time in the tissue of those large plants that we call trees. The beauty of wood as a fuel was that it was portable – a source of energy that was mobile and controllable. The portability of energy is also central to modern human energy systems. Recent human history, especially from the industrial

Table 1.1 *Net plant production across selected ecosystems (megajoules per square metre)*

Ecosystem	Production
Extreme desert	0.06
Open ocean	2.4
Continental shelf	6.6
Lakes and streams	9.4
Temperate grasslands	9.4
Woodlands and shrublands	11.3
Agricultural land	12.2
Forest — coniferous	15.1
— temperate	24.5
— tropical	37.7
Estuaries, swamps and marshes	37.7
Average — for oceans	2.9
— for land	13.8
— for total Earth	6.0

Source: Adapted from Kormondy 1976.

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revolution onwards, has been the story of utilising higher quality and more portable sources of energy.

Energy: recent history

Basic to the modern economy is a supply of *fuels*, which are those substances that we use as carriers of energy, and which allow us not only to produce vastly more of the *heat* that wood allowed us to enjoy, but also to convert large amounts of this into *mechanical* energy to perform tasks previously unthinkable.

For millennia, the main fuels used by humans were wood and other *biofuels* such as dung. This provided heat to warm themselves, to cook food, to bake clays or to smelt metals. They also discovered means of harnessing other sources of mechanical energy. At first, this was in the form of the somatic energy of draught animals and, later, the extrasomatic energy of moving air (sails, wind-driven mills) and moving water (water-driven mills). These sources of energy were very useful but not particularly reliable, of high quality, or portable.

Two forms of fuel exist: *chemical* (which can be burned to give off heat) and *nuclear* (which can undergo fission). Chemical fuels – coal, oil, gas, wood and other biofuels – are by far the more important in the global energy system, either used in their primary form or refined or converted into other forms (such as crude oil to petrol, or coal to electricity). All these chemical fuels are stored forms of solar energy – in wood, or that energy stored long ago in the dead bodies of organisms that we now call the *fossil fuels*: coal, oil and natural gas. Similarly, the smaller amounts of energy captured as hydro-electricity (derived from moving water), from wind or various forms of solar collectors are solar energy that we can convert. Nuclear energy is different, being the inner energy of atoms which humans now can release, and which has never before been a part of the solar-driven energy system of the Earth. Fuels may be *primary* or *derived*. For example, oil or coal may be combusted directly in a boiler as a primary fuel, or in a generation plant to produce electricity, a derived fuel.

An important difference between sources of energy is whether they are *renewable* or *non-renewable*. At present our society relies primarily on non-renewable forms of extrasomatic energy: oil, coal, gas and nuclear. Dependent on the rate of use and the size of the resource stock, such energy sources will at some stage be exhausted. The use of renewable forms of energy does not necessarily involve a run-down of a finite resource stock. This category includes sources such as solar, hydro, wind and tidal energy and (if managed properly) *biomass* energy sources such as grain alcohol or fuelwood. Apart from these stock aspects, renewable energy sources in general involve the production of far less troublesome waste products such as carbon dioxide or various air pollutants than do non-renewable sources. This is especially the case for solar, wind, hydro and tidal power, but somewhat less the case for biomass fuels. For both these reasons, renewable energy is preferable, from the standpoint of long-term supply and environmental and health issues.

The beginning of the modern phase of human history – *the high-energy phase* – can be dated as around the same as the beginning of what is more broadly known as the Industrial Revolution (Boyden 1987). The steam engine, at first powered by wood, was soon stoked with coal and gave humans significant amounts of portable, controllable mechanical energy for the first time. Later, the use of oil, the development of the internal combustion engine, and the discovery and use of electricity expanded the available supply of energy, making possible the heat transport machines and the communications systems which support modern civilizations.

In 1650 AD, prior to the Industrial Revolution, the somatic energy use of the world's human population was in the order of 2000 petajoules (PJ) and the extrasomatic energy use about 4000 PJ. In 1990, total human energy use was about 360,000 PJ, about 95% of this being extrasomatic energy derived mostly from fossil chemical fuels.

Energy: problems, addictions and traps

As previously stated, the creation of new energy systems is a challenge of great magnitude. This is precisely because energy is so fundamental and important; because it is a basic ingredient of every action and process in a human society. The World Commission on Environment and Development (1987: 15) put it thus (*emphasis added*):

> A safe, environmentally sound, and economically viable energy pathway that will sustain human progress into the distant future is clearly imperative. It is also possible. *But it will require new dimensions of political will and institutional cooperation to achieve it.*

Particularly in the industrialised world, social and economic systems have evolved that are completely dependent upon unending and large inputs of fossil fuels. Many cities and towns are so structured that the lack of a motor car is a serious social and economic disadvantage. We are reliant on goods that are produced at some distance and so depend on energy-intensive transport systems. In fact, the spatial arrangemnts of industrial societies are very much a product of their energy systems

(Owens 1986). Industrial agriculture requires large energy inputs, our communications systems are based on electricity, and the manufactured products we consume, to varying intensities, require inputs of energy in their production. Modern societies have certainly become addicted to large quantities of cheap and convenient energy. Our social, economic, production and political systems are dependent on it. Moreover, the geopolitics of the modern world is strongly influenced by energy (Tsai 1989; Kapstein 1990).

But it has become increasingly obvious that, while it may have seemed a 'good idea at the time', this addiction has many drawbacks at first not obvious. Some of these were mentioned earlier, and are discussed in more detail in the next chapter. In this way, energy is a classic example of what has been dubbed a *social trap*, a term coined by Platt (1973). Social traps are defined by Brechner and Linder (1981: 29) as:

> ... situations where the short-term consequences for a behaviour are positive and the long-term consequences are negative.

Driving a car to purchase goods, cooking using electricity, heating a non-insulated home – these are convenient behaviours with positive short-term consequences. Air pollution, run-down of resource stocks, global climate change, urban congestion – these are the inconvenient long-term consequences. At a time before such conveniences were invented, humans obviously did without them, achieving their ends by some other means, but now most people in industrialised societies could scarcely envisage life in their absence. Once introduced, many innovations are adopted at an astoundingly rapid rate and become classic examples of the principle of *technoaddiction* (Boyden 1987).

The essence of a social trap is that it is indeed a trap; easy to enter but hard to escape. We have entered the trap and have benefited from enormous increases in energy use, but can now see the long-term consequences and are beginning to seek ways to avoid or lessen these. In social trap analysis, various solutions have been proposed (adapted from Brechner and Linder 1981) to:

- reduce the delay period between the behaviour or action and the negative consequence (that is, to make the consequence more immediately obvious);
- increase or to create short-term costs or negative consequences associated with the behaviour or action (that is, create disincentives to discourage the behaviour);
- reward or otherwise reinforce alternative behaviours or actions which do not have the long-term negative consequence (that is, offer incentives for change);