1 What is energy sustainability?

We frequently hear that our energy system is not sustainable. This certainly sounds right.

Our economies, especially those of industrialized countries, are completely dependent on fossil fuels – coal, oil and natural gas. These are non-renewable resources that we shall exhaust one day, perhaps soon. Fossil fuels provide energy via combustion and in the process release emissions that are toxic to animals and plants. Some of these emissions may be changing the earth's climate. Indeed, each stage in the exploration, extraction, processing, transportation and consumption of fossil fuels has known impacts and suspected risks for humans and ecosystems.

Surely the solution is to wean ourselves quickly off of fossil fuels – for there are ready alternatives. We can use energy much more efficiently. Reduce our energy consumption and we equally reduce emissions, slowing the depletion of fossil fuels at the same time. We can increase our use of nuclear power. It has negligible emissions and is virtually inexhaustible. We can rekindle our pre-industrial dependence on renewable energy, this time with advanced technologies that meet the needs of the information age for high quality, reliable energy.

In the more than twenty years that I have devoted to researching the relationship between energy, the environment and the economy – first as a graduate student, then combining duties as professor, policy advisor and five years chairing an energy regulatory agency – I have assumed that the shift to a sustainable energy system would entail a transition away from fossil fuels. I have also assumed that I would witness much of this transition during my lifetime.

My basic premise was that the way we consume the earth's fossil fuels must certainly be unsustainable given that fossil fuels are a rich and irreplaceable endowment produced from millennia of biological and geological processes. Consumption of them today leaves nothing for the future. Our appetite is clearly out of control, given that half of the oil consumption throughout human history has occurred since 1980. Moreover, our appetite is highly wasteful. We are unwilling to acquire more energy efficient equipment that should repay its extra up-front cost many times over. We leave the car running while chatting to a friend. We acquire frivolous energy-consuming products whose contribution to our well-being is questionable at best. Then there is the human and ecological mess of our addiction to fossil fuels: oil spills on land and sea, emissions that cause smog, acid rain and perhaps climate change.

I saw the reliance on nuclear energy as no better – and even more disquieting. The accidents at Three Mile Island in the US in 1979 and Chernobyl in the USSR in 1985 occurred during my university studies, leaving an enduring impression – especially when Chernobyl's radioactive cloud settled over the village in France where I lived at the time. The assumption that humans can safely handle radioactive waste seemed arrogant. Leaving a stockpile of such material for others to deal with went completely against my values of taking responsibility for one's impact on the earth and one's obligations to future generations.

To make matters worse, nuclear and fossil fuels fared poorly in the very field where they were expected to excel – financial performance. Almost everywhere, the costs of nuclear power ended up higher than promised, even when these costs failed to include all the up-front development subsidies, the full insurance liability, and the eventual decommissioning of old plants and permanent storage of radioactive fuel, equipment and structures. The initial oil price shocks of the 1970s and early 1980s were followed by price spikes in the 1991 Gulf war and then the 2003 Iraq war. Combined with the high prices of the last few years, these events convinced many experts and non-experts that price volatility is a perpetual threat with fossil fuels, regardless of whether the cause is impending resource depletion or geopolitically created shortages.

In contrast, because renewables rely on the free flows of nature – especially the sun – real or artificial scarcities seemed impossible. I remember a saying from the 1980s: "the oil companies cannot get between us and the sun's rays, but they will keep trying." Efficiency and renewables were associated with the careful husbanding of natural endowments, while harmonizing our lives and our economy at a smaller scale more in tune with the dispersed and unique character of each renewable energy source. While the initial capital costs of renewable energy might sometimes be high, its operating costs would be stable and predictable, reflecting the continuous and free energy from the sun and other natural sources. Surely a renewables-based economy provided the blueprint for how to live sustainably on this earth.

I therefore focused my career research efforts on the technical and economic analysis of energy efficiency and renewable energy, and the policies needed to foster these two energy alternatives. My longstanding preference for efficiency and renewables is a view that has finally gained support in recent years, usually for reasons that match my own. Today, we often hear these arguments. What is the point of greater dependence on fossil fuels if we must eventually run out? What is the point of trying to clean up fossil fuels when we keep discovering new problems from using them? Shouldn't we save fossil fuels in case we have a special need for them in future? How can nuclear be sustainable with its ongoing risks of catastrophic accidents, on the one hand, and of low-level radiation exposure from generating plants and facilities for waste treatment, transport and storage on the other? How can we feel secure about a dramatic, worldwide expansion of nuclear generation given the threat that such technology will be diverted to military and terrorist ends?

The answer must be to begin immediately the transition away from fossil fuels to a high efficiency, renewables-based energy system, especially before the rapidly growing energy needs of developing countries overwhelm whatever small gains we have made in cleaning up fossil fuels and reducing the risks of the existing nuclear power industry. This position is advocated today not just by environmentalists but also by international agencies, corporations, energy experts and politicians. These recent quotes illustrate this widely held view.

The 2001 report of the Global Environmental Facility states:

> A transition to renewables is inevitable, not only because fossil fuel supplies will run out – large reserves of oil, coal and gas remain in the world – but because the costs and risks of using these supplies will continue to increase relative to renewable energy.[1]

L. Brown, in his 2001 book *Eco-Economy*, says:

> As the new century begins, the Sun is setting on the fossil fuel era . . . It is this desire for clean, climate-benign fuels – not the depletion of fossil fuels – that is driving the global transition to the solar/hydrogen age.[2]

In his 2001 book *Tomorrow's Energy*, P. Hoffman writes:

> Hydrogen could be generated in a fusion reactor itself, providing another pathway toward a sustainable energy future with no environmental damage and virtually unlimited fuel supply. For the moment, however, solar and renewables represent the best complementary energy resource for hydrogen production in terms of environmental benefits.[3]

With the 2001 printing of his book *The Carbon War*, J. Leggett seethes:

> Exxon, Mobil, Texaco and the other residually unrepentant thugs of the corporate world look like continuing to sign the cheques that bankroll the carbon club's crimes against humanity, along with their kindred spirits in the auto, coal and utility industries. They may well enjoy minor victories along the way. But they have already lost the pivotal battle in the carbon war. The solar revolution is coming. It is now inevitable.[4]

In describing the transition to a sustainable energy system in their 2002 book *Great Transition*, P. Raskin and co-authors say:

> Climate stabilization at safe levels requires transcending the age of fossil fuels. The path to a solar future would be bridged by greater reliance on natural gas, a relatively low-polluting fossil fuel, and modern biomass technologies.[5]

H. Scheer, in his 2002 book *The Solar Economy: Renewable Energy for a Sustainable Global Future*, says:

> An energy supply that protects the climate and the environment must necessarily be based on renewable, not fossil or nuclear energy, which means replacing the current system with more efficient energy technology using renewable resources.[6]

In his 2002 book *The Hydrogen Economy*, J. Rifkin states:

> If the fossil-fuel era is passing, what can replace it? A new energy regime lies before us whose nature and character are as different from that of fossil fuels as the latter was different from the wood-burning energy that preceded it. Hydrogen is the lightest and most ubiquitous element found in the universe. When harnessed as a form of energy, it becomes the forever fuel. It never runs out, and, because it contains not a single carbon atom, it emits no carbon dioxide.[7]

H. Geller, in his 2003 book *Energy Revolution*, says:

A sustainable energy future is possible through much greater energy efficiency and much greater reliance on renewable energy sources compared to current energy patterns and trends. . . . Shifting from fossil fuels to renewable energy sources in the coming decades would address all the problems associated with a business-as-usual energy future.[8]

Referring to the impact of impending oil scarcity in his 2003 book *The Party's Over*, R. Heinberg says:

The core message of this book is that industrial civilization is based on the consumption of energy resources that are inherently limited in quantity, and that are about to become scarce. When they do, competition for what remains will trigger dramatic economic and geopolitical events; in the end, it may be impossible for even a single nation to sustain industrialism as we have known it during the twentieth century.[9]

On the cover of *The End of Oil*, a 2004 book by P. Roberts, it is stated:

the side effects of an oil-based society – economic volatility, geopolitical conflict, and the climate-changing impact of hydrocarbon pollution – will render fossil fuels an all but unacceptable solution.[10]

Finally, in his 2004 book *Out of Gas: The End of the Age of Oil*, D. Goodstein confidently asserts:

Civilization as we know it will come to an end sometime in this century unless we can find a way to live without fossil fuels.[11]

I found these quotes quickly and easily, and I knew I would because, as an avid follower of both popular and academic writing on energy sustainability, I encounter similar quotes every week. Indeed, I hear this sentiment expressed much more frequently today than I did fifteen or even five years ago.

As an academic researcher and policy advisor, this seems like an ideal time to ride the wave of efficiency and renewables. There is lots of research money available. Industry and environmentalists are starting to say the same things about the need to abandon the fossil fuel ship. Politicians are listening. The media is onside. The public is receptive.

But as is obvious from the title of this book, my research has gone in quite a different direction in the past four years. As I started to look more closely at our global energy options, I began to entertain, and then research more vigorously, a counter-intuitive hypothesis about the future of our energy system. Is it really necessary that we quickly reject fossil fuels? Is it possible that our supplies of fossil fuels are in fact still plentiful even if our production of them in one form – conventional oil – might be reaching its peak? Is it possible that we might develop, at a reasonable cost, ways of extracting useful energy from fossil fuels without causing harm to the biosphere and ourselves? Is it really true that abandoning oil would reduce geopolitical conflict and price volatility in energy markets? Or, do these phenomena happen mostly for other reasons?

What about a critical and popular concept like sustainability? Fossil fuels are a finite resource that we are using up. They cannot be part of a sustainable energy system. Or can they? The more I thought about the issue, and the more I researched it, the more I found myself challenging even my assumption about the elements and character of a sustainable energy system. And as I read more and more books and articles proclaiming the end of the age of fossil fuels, I started to notice more and more unfounded assumptions embedded in these proclamations – assumptions about resource magnitudes, technological potential, the function of markets, substitution between resources, and how one might define and determine the sustainability of a system.

Questioning these assumptions has taken me down an unexpected path indeed. It has led me to develop the hypothesis that fossil fuels can continue to play a significant role in the global energy system in this century, and probably long beyond, even though we might characterize such a system as sustainable. But given how I just described fossil fuels – their non-renewable and polluting character – this seems impossible. This book explores how I arrived at this unexpected conclusion. I begin the exploration at a general level by outlining in this introductory chapter some fundamental concepts: the definition and basic characteristics of a sustainable energy system, our experiences with using fossil fuels, and the major options for our energy system.

1.1 What is the energy system and how do we determine its sustainability?

Energy analysts refer to an energy system as the "combined processes of acquiring and using energy in a given society or economy." Such a system includes therefore sources of *primary energy*, the forms of *secondary energy* that we transform these primary sources into, and the final *energy services* (also known as *tertiary energy* or *energy end-uses*) such as lighting, mobility, space heating and cooling. We receive energy services by using secondary energy in end-use devices (or technologies) like lights, cars, furnaces and fridges.

Primary energy

Although energy appears to us on the earth's surface in different guises, these are all in some way the product of only two primary sources of energy. These are gravitational force and the conversion of mass into energy via nuclear reaction.

The gravitational force of the moon on the earth causes tidal movement of water, and the gravitational force of the earth causes earthward movement of objects, such as the kinetic energy in water flowing downhill. Gravitational forces of accreting mass in the earlier development of our solar system caused the consolidation and compression into larger bodies that eventually led to the creation of the earth. The earth's hot interior is the legacy of these earlier gravitational processes and the radioactive decay of long-lived radioactive elements – notably uranium, thorium and radium – that were incorporated into the earth at the time of its formation. Thus, geothermal energy that is now available near the earth's surface, especially in volcanic zones, might be interpreted as a combined result of gravitational force and nuclear reaction.

Mass is converted into energy either by the nuclear fusion of two light atoms or by the nuclear fission of a heavy atom. Naturally occurring nuclear fission does not provide much energy at the earth's surface, but in nuclear power plants humans have learned to concentrate and control fission processes to split uranium atoms and capture the resulting heat to drive steam turbines that generate electricity. Solar energy, resulting from the nuclear fusion in the sun of hydrogen atoms into helium, is responsible for most forms of energy found naturally at the earth's surface; at 174,000 terawatts (TW), solar radiation dwarfs all other natural energy sources and is 10,000 times greater than the current human use of energy. The sun's heat energy produces wind, waves (from wind), ocean currents and hydropower, as solar thermal energy combines with gravity to produce the hydrological cycle. The sun's light energy drives the growth of plants via photosynthesis, which is therefore responsible for chemical energy from biomass (forest and crop residues, animal and human waste). Humans have also learned to generate electricity directly from solar light energy via photovoltaics – using cells, made from silicon or other materials, whose electrons are released when struck by light energy (photons). Researchers are studying how to mimic the fusion process in the sun in a controlled reaction that they hope will one day produce heat for generating electricity, as we do today with nuclear fission.

Fossil fuels are a byproduct of solar energy. Over millions of years some of the remains of plants and animals have been preserved in sedimentary layers and then eventually transformed and concentrated under tectonic forces that subjected them to higher pressures and temperatures. Coal is mostly the remains of swamp plants that decomposed into peat and were eventually buried and subjected to higher pressure. Oil and natural gas are assumed to originate primarily from plankton that fell to the ocean floor near continental shorelines where it was covered by layers of sediment and eventually transformed into gaseous and liquid hydrocarbons through high pressure and temperature over millions of years.

In discussions over the past few years, I have suggested to my graduate students – environmentally oriented as they are – that fossil fuels are nothing more than solar energy, conveniently concentrated by nature for ease of use. I enjoy the heated discussions that follow. In frustration, one group referred to me as their "fossil fool" – affectionately I like to assume. My retort was that we should actually refer to solar energy as nuclear energy, given the primary energy role of nuclear fusion in the sun. Somehow this made me "a nuclear advocate." My point was that the closer you look at the sources of energy the more difficult it is to stick to simple classifications like fossil fuels, nuclear, and renewables. These sources of energy are more interrelated than many people assume. Maybe it was the need to challenge these comfortable assumptions of my students and myself that eventually made me more receptive to the hypothesis I entertain in this book.

In pre-industrial times there was little processing of primary energy prior to use. The dominant source of energy was heat from wood combustion. Usually, however, we process and transform primary energy in some way to render it easier to use or to remove unpleasant properties. We call the resulting products secondary energy.

Secondary energy

Coal is only slightly transformed before its use in electricity generation and steel production, although we can extract methane (natural gas) directly from it as coal-bed methane, and in the past century (and still in some places today) coal was gasified and distributed as *town gas* in cities. Before the Second World War, Germany's scientists developed ways of producing *synthetic gasoline* from coal as a precaution against wartime disruption of their crude oil imports, and relied on this extensively in the later years of the war. This process is still used in South Africa. Crude oil is transformed at an oil refinery into a range of refined petroleum products including gasoline, diesel, propane, kerosene and heavy heating oil. Raw natural gas requires processing to extract sulphur, liquids, and other gases, and to inject odorous compounds to help consumers detect leaks.

Some forms of secondary energy differ dramatically from the original primary source. Electricity is not available in nature – except during a lightning storm or sometimes when I touch my car door after driving – but it can be produced from uranium via nuclear fission, from fossil fuels and biomass via combustion, from the heat of geothermal energy, from solar light energy via photovoltaics, and from solar heat energy and gravitational force via the resulting wind, waves, hydropower and tides, whose mechanical energy can spin electricity-generating turbines. Hydrogen is another form of secondary energy that is not freely available in nature but can be produced from other primary and secondary forms, including the removal of hydrogen from hydrocarbon compounds (fossil fuels and biomass) or the electrolysis of water (separating oxygen and hydrogen) using electricity. As these last examples suggest, energy systems can get complicated, with several transformations possible prior to providing final energy services to consumers.

Hydrogen and electricity are frequently seen as essential components of a sustainable energy system because both appear to have negligible impacts on people or ecosystems, making them ideal forms of secondary energy for delivery to homes, offices and factories, and for fueling vehicles. The properties of electricity are well known and its risks, like electrocution and fire, are understood and accepted. The properties of hydrogen, in contrast, are not well known, and there are a wide range of views about what the production, transport and use of

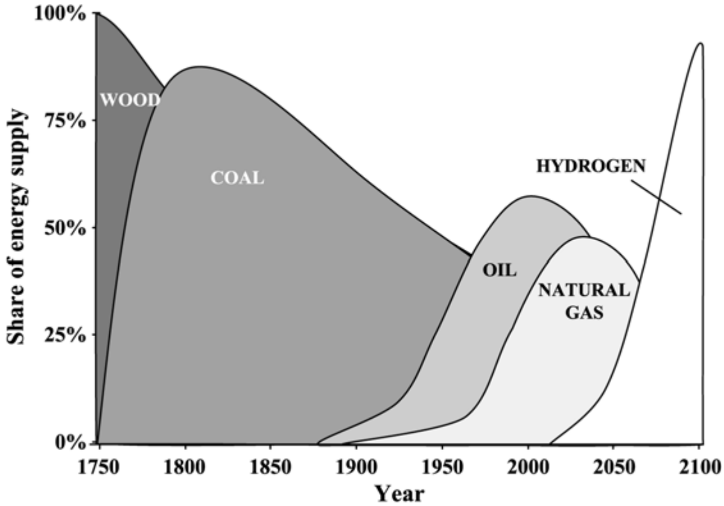

Figure 1.1. A misleading view of dominant energy forms.

this fuel might entail in terms of impacts and risks for people and the environment.

There are misperceptions about the role of hydrogen, with some commentators and even researchers describing it as if it were a primary source of energy (see the earlier quote of J. Rifkin in which he suggests that the hydrogen era will follow the fossil fuel era). Figure 1.1, a diagram that I have seen at more than one conference, depicts the evolution of human energy sources over time, and predicts a dominant role for hydrogen in future. The diagram shows how we have evolved from a global energy system dominated by wood and other forms of biomass to one in which coal, oil and then natural gas dominates. The diagram suggests that a hydrogen era will follow that of natural gas. However, there is a serious conceptual problem with this diagram; wood, coal, oil and natural gas are all primary sources of energy while hydrogen, like electricity, is not. A primary energy source is needed to produce the hydrogen. This source might well be wood, coal, oil, natural gas or some energy source not even in the diagram, such as nuclear or solar energy.

Many people now believe that hydrogen will become a dominant form of secondary energy in this century – and several recent books