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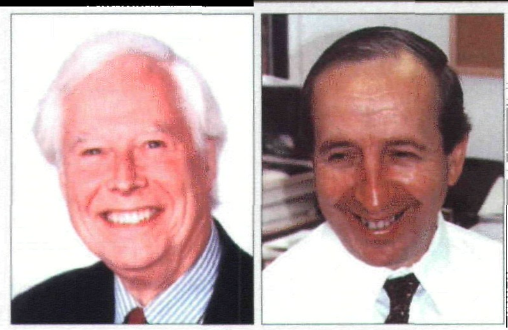
Do we need nuclear power?

With rising fuel costs, concerns about global warming and the growing demand from the developing world for energy, the burning question is whether the world needs nuclear power. **Peter Hodgson**, a nuclear physicist, says yes. **Dennis Anderson**, an economist, says that we should first explore the possibilities of renewables and other forms of energy

Joint introduction

Our civilization and our standard of living depend on an adequate supply of energy. Without energy, we would not be able to heat our homes or cook our food. Long-distance travel and communication would become impossible, and our factories could no longer produce the goods that we need.



Peter Hodgson (left) and Dennis Anderson (right)

A century ago the world's energy came almost wholly from coal and "traditional" sources, such as wood, crop residues and animal dung. These are still major sources of energy, particularly in developing countries, where 2 billion people are without access to, or cannot afford, modern energy forms. Wood and dung are estimated to provide an amount of energy equivalent to 1 billion tonnes of oil each year; it is sobering to realize that this is 1.6 times more energy than is provided worldwide by nuclear power, and is about the same as the amount of energy provided by coal in Europe and the US combined (see table on page 17).

During the 20th century, the world's commercial output and population increased more rapidly than ever before, as did energy consumption, which rose more than tenfold, with a major shift towards oil and gas fuels, and to hydroelectricity and nuclear power. Most of the growth was in industrial nations, where the per capita consumption of commercial fuels is about 10 times that in the developing world.

Energy markets in the industrial countries are maturing, and may even peak and decline with continued improvements in energy efficiency. The last two centuries saw energy efficiency increase enormously – in motive power, electricity generation, lighting, in the use and conservation of heat, and in an array of other applications. There is no evidence that further gains will not be achieved in the future – for example through the use of fuel cells for transport, which could lead to a two- or threefold increase in fuel efficiency relative to that of the internal combustion engine, and through distributed sources of combined heat and power.

The situation is different in developing countries, where billions of people have hardly enough energy to survive, let alone enough to increase their living standards. If they are to achieve prosperity, their energy needs – which are doubling every 15 years – will have to be met. Moreover, their population will soon be 7–10 times greater than that of the industrial world, and (with the sad exception of several African countries) economic growth is much higher than it is for industrial nations.

If we assume that, after allowing for gains in energy efficiency, the developing world eventually uses only half of the energy per capita consumed by industrial nations today, then the world's energy consumption will still rise more than threefold. Developing nations will therefore need about 5×10^6 MW of new electricity-generating capacity in the coming decades, compared with the 1×10^6 MW they have today and the 2×10^6 MW in the industrial nations. (Electricity generation accounts for only about one-fifth of our final energy consumption – the rest mainly being for transport and heating.)

Our common ground in debating the question "Do we need nuclear power?" is therefore the fact that the world is likely to need yet more energy, despite the immense amount of energy consumed today. The environmental problems associated with energy production and use will also need to be addressed, including local and regional pollution, and the much-discussed problem of global warming.

Peter Hodgson and Dennis Anderson

YES

Finding ways of satisfying our energy needs is such an urgent problem that we must consider all possible sources, and evaluate them as objectively as possible, *writes Peter Hodgson.* In doing so, it is useful to apply the following criteria: capacity, cost, safety, reliability and environmental effects. No source can satisfy all our energy needs, and although there are several small-scale energy sources, such as solar panels for satellites, we must focus on the major sources.

Wood was a major energy source in ancient times, and is still extensively used in developing countries. It is, however, impractical as a major energy source in developed countries as it occupies much land and adds to atmospheric pollution. Oil, meanwhile, is fast running out and is needed by the petrochemical industry. It is wasteful to burn it, which also adds to pollution. The same applies to natural gas.

Hydropower is an important source of energy, particularly as it is renewable and does not pollute the atmosphere. However, it uses up valuable land and, in any case, the number of suitable rivers is limited. It is unlikely that hydropower will provide for more than about 8% of our energy needs. Tidal power is even more limited by geographical considerations.

The remaining sources – such as wind, solar and geothermal – account for only a few per cent of the global energy consumption. In addition, some of them are unreliable (wind and solar) or intermittent (tidal) and relatively costly. And although the energy in sunshine, wind, waves and tides is enough to satisfy our needs millions of times over, the difficulty is in harnessing these sources in a usable form. Despite continued efforts, wind and solar sources contribute less than 0.5% of our energy production (see table on page 17).

This leaves only coal as a major source of energy for at least a few centuries. However, a typical coal-fired power station emits some 11 million tonnes of carbon dioxide each year, as well as 1 million tonnes of ash, 500 000 tonnes of gypsum, 29 000 tonnes of nitrous oxide, 21 000 tonnes of sludge, 16 000 tonnes of sulphur dioxide, 1000 tonnes of dust and smaller amounts of other chemicals, such as calcium, potassium, titanium and arsenic. To produce 1 gigawatt-year of electricity requires about 3.5 million tonnes of coal – and this contains over

5 tonnes of uranium. Most of the by-products are caught by filters, but a few thousand tonnes of ash escape, carrying with it a corresponding fraction of the uranium. This accounts for the radioactivity emitted by coal-fired power stations. All the gaseous waste is poured into the air we breathe, and damages our health. To continue to rely on coal could lead to widespread environmental damage and unpredictable climate change.

Can nuclear provide the energy we need? It already generates about 20% of the world's electricity, including 50% in Western Europe and 80% in France. It is reliable, having high "load factors" – typically more than 90% – with nearly all of the remaining time spent on planned maintenance. Its long-term costs are similar to those of coal. It has little harmful effect on the environment and it is safer than all other sources, apart from natural gas.

Nuclear power only differs from other energy sources in that it emits nuclear radiations. The interior of a nuclear reactor is highly radioactive, and the spent fuel has to be removed periodically for reprocessing. However, the techniques for doing this are well developed and can be carried out safely. The relatively small volumes of highly radioactive residues (nuclear waste) are first stored above ground for several decades to allow the short-lived isotopes to decay, the rest being fused into a insoluble ceramic blocks, encased in stainless-steel containers and buried far below ground in a stable geological formation.

Nuclear reactors can also be improved. While current "thermal reactors" burn only uranium-235, which accounts for just 0.7% of natural uranium, so-called "fast reactors" can burn the remaining 99.3% of the uranium. One reason why fast reactors are not used is because they are more difficult to build, but they will become more economic as uranium becomes more expensive – and could eventually take over from thermal reactors.

Before then, other reactor designs may become available. A particularly promising line of research, which is being pioneered by the Nobel-prize winning physicist Carlo Rubbia and others, is into reactors that depend on spallation neutrons from a proton accelerator. The protons hit a target of a heavy metal, such as tungsten, producing a shower of neutrons that go into a sub-critical reactor assembly. This makes the reactor go critical, thereby generating power. Such reactors are easily controlled because the reaction stops as soon as the accelerator is switched off. The neutron fluxes are also so high that the radioactive wastes can be burnt inside the reactor. These are both highly desirable environmental features. "Pebble-bed" reactors are another promising development.

In the longer term, I have high hopes that fusion energy will ultimately become available. Intensive work is in progress on several possible designs for a fusion reactor. These reactors need deuterium, which is present in water in the proportion of about one part in five thousand. The energy available from fusion reactors is therefore practically limitless.

It is indeed fortunate that, just as other major energy sources are becoming exhausted or are recognized as seriously polluting, a new energy source – nuclear power – has become available to meet our needs.

It could cost the Earth – how can we meet our energy needs without damaging the environment?

Global primary-energy consumption

Energy source	1860	1900	1950	2000
Traditional (wood, dung, etc)	270	330	470	~1000
Coal	100	470	1300	2220
Oil		20	470	3400
Natural gas			170	2020
Hydro-electric		10	120	230
Nuclear power				630
Renewable (other than hydro)				~200
Total	**370**	**830**	**2530**	**~9700**

(In million tonnes of oil (toe) equivalent energy)
Sources. For 1860, 1900 and 1950: *Nuclear Energy in Industry* (1957 Crowther); figures converted from coal-equivalent to oil-equivalent energy by dividing by 1.5. For 2000: *Statistical Review of World Energy* (1999 BP Amoco), trended up to 2000; except traditional energy, from *Rural Energy and Development* (1996 World Bank). For primary energy, BP assumes that one tonne of oil produces 4000 kWh in a modern power station.

NO

I agree with the relevance of Hodgson's five criteria: capacity, cost, safety, reliability and the environment, *writes Dennis Anderson*. But I find he applies them unevenly toward the three main energy sources under discussion – fossil fuels, renewable energy and nuclear power – with a skew against both fossil fuels and renewable energy. Let me take fossil fuels first, since there is a moral in this for both nuclear power and renewable energy.

The United Nations "Atoms for Peace" conferences in 1955 and 1957, which set the stage for the expansion of the nuclear industry, were unambiguous about the need for nuclear power. The view was that fossil fuels would last for about 75 years and that, by the end of the 20th century, we would be faced with major energy crises unless we had nuclear power. The costs of fossil fuels would rise exponentially, while those of nuclear power would fall.

However, the opposite has happened. Fossil fuels have proven to be abundant and less expensive than nuclear power. Estimates of fossil-fuel reserves are enormous, especially of gas. "Commercially proven" reserves – those that companies have access to and declare in their assets are a poor guide to actual reserves, which include unexplored resources and unconventional resources such as tar sands, shale oils and gas hydrates.

Estimates suggest that, at current extraction rates, we have over 200 years' supply of oil, 450 for natural gas and over 1500 for coal, the weighted average being nearly 700 years (see Rogner in further reading). Even this is an understatement, since it excludes natural-gas hydrates in the permafrost and under the ocean floors, and other sources that together are thought to amount to five times these values.

Moreover, the oil, gas and coal industries have made tremendous advances in exploration and production, and the electricity industry is steadily improving the thermal efficiency of fossil-fuel power stations. Estimates of reserves have increased more than tenfold, and costs have declined relative to those of nuclear power. Indeed, if nuclear power were to compete commercially with a natural-gas-fired power station, it would need a subsidy of more than £1bn per gigawatt.

It is, of course, easy to speak with the wisdom of hindsight, and to overlook the uncertainties and risks that the energy industry faced when nuclear-power programmes were being put in place. In the 1950s nuclear power held the promise of unlimited energy in an era when coal mining was an arduous, dangerous and unhealthy occupation for millions of workers (as it still is in China and India), when fuel shortages were common, and when coal burning in homes and industry was the source of intolerable levels of local pollution.

Nevertheless, nuclear power has been unable to compete in terms of cost with fossil fuels, and there is no commercial interest in it outside state-run electricity sectors. The subsidies for nuclear power over the past five decades have been colossal – about a hundred times the amount we have spent on developing renewable energy, for example – and further immense subsidies will be required to deal with the legacy of nuclear wastes and the decommissioning of power stations. Indeed, following the privatization of the electricity industry in the late 1980s, the UK introduced a Non Fossil Fuel Obligation (NFFO) to support nuclear power; it injected £8bn of subsidies into the industry *after* it had been sold off, while another

£5bn is reportedly needed to deal with the decommissioning of the Dounreay nuclear facility. The NFFO, in contrast, injected just £750m (less than 10% of the funds) into renewable energy.

It is true that nuclear power makes a sizeable contribution to energy supplies in France and the UK, and that global production grew from near zero to the equivalent of 630 million tonnes of oil (toe) per year between 1960 and 2000. But the energy obtained from biomass – albeit unsustainably gathered over large areas – also increased by almost as much, in absolute terms, as that obtained from nuclear power. The contribution of fossil fuels rose by seven times this amount, notwithstanding the predictions that they would be nearly exhausted by the year 2000.

In terms of capacity and cost, it is thus difficult to make a good case for nuclear power. Fossil fuels are more than sufficient to meet the world's energy needs economically, not least in developing countries. Will environmental concerns change this? In response to successions of clean-air acts and environmental controls introduced in industrial nations, all sectors of the energy industry have made immense strides in reducing local and regional pollution per unit of energy consumption.

With the partial exception of nitrous oxides, the development of "clean" technologies and fuels is enabling pollution per unit of energy use to be reduced by several orders of magnitude. We have seen major reductions in local and regional pollution where these technologies and practices have been introduced: reductions of smog, lead in fuels and acid deposition in Europe and the US being striking examples. The associated costs have, moreover, proved to be small compared with the overall costs of energy use, and have sometimes been negative, with the "clean" practice being more efficient than the polluting practice it displaced. Further reductions are still possible, with hybrid vehicles and fuel cells holding considerable promise. Countries taking advantage of these technological developments have been able to use more energy with less pollution and have found themselves economically better off.

The fossil-fuel industry has thus responded remarkably well to local and regional pollution problems, and there is no reason why societies cannot enjoy the benefits of using these sources while striving to improve the local and regional environment. I shall tend to the global environment later.

YES

Anderson observes that fossil fuels have proven to be abundant and less expensive than nuclear power. It is not surprising that estimates of reserves differ, because surveys are inevitably incomplete. Furthermore, the quantities available depend on how much we are prepared to pay for extraction. Relative costs are difficult to estimate because nuclear costs depend on the lifetime of the reactor, which may be as long as 60 years. A small fraction of the output invested each year easily pays for decommissioning, and reactors are now designed to facilitate this process. The cost of nuclear power relative to fossil fuels would be very different if realistic estimates of the cost of pollution and climate change were also included. In the short term, fossil fuels may appear less expensive, but it is the long term that is more important.

Better by design – "fast" reactors like the one tested at Dounreay could make nuclear power cheaper

The Belgian government recently set up a commission to examine the options for electricity generation. Taking into account fuel costs, non-fuel costs (investment, operation and maintenance), external costs (air pollution, noise and greenhouse gases) as well as the cost of construction, grid connection and decommissioning, the commission estimated that it will cost BFr 2.34 to generate every kilowatt-hour of electricity from coal in 2010. The equivalent figures were 1.74 for gas, wind as 1.85 (seashore), 2.39 (offshore) and 3.26 (inland), but just 1.22–1.28 for nuclear power. In other words, nuclear power is not only more reliable, safer and less detrimental to the environment than the alternatives, but also substantially cheaper.

In his book *The Earth Under Threat*, Sir Ghillean Prance, former director of the Royal Botanical Gardens at Kew, describes in graphic detail the devastating effect on animal and plant life already attributable to climate change (see further reading). Many species, such as the golden toad in Costa Rica, have become extinct. This can be dismissed as anecdotal and lacking in statistical basis. Who cares about the golden toad? Well, I do, as I care about all threatened species.

Scientists on the UN's International Panel for Climate Change (IPCC) have amassed impressive evidence that climate change is real. Their work indicates that in the next 100 years average global temperatures will rise by several degrees and the sea level by 50–100 cm. There are, of course, many uncertainties, but it is prudent to take climate change seriously. Many of its potentially devastating effects are directly attributable to the carbon dioxide emitted when fossil fuels are burnt. Meanwhile, impurities in fossil fuels cause acid rain, which is already adversely affecting rivers, lakes and forests. While some countries are reducing the levels of pollution, this must be done world wide. It is therefore essential to eliminate fossil-fuel power stations.

As for wind and solar power, they contributed only 0.15% of the world's energy production in 2000 and disfigure large areas of land. They are also relatively expensive and five times as dangerous as nuclear power as measured by deaths from all causes during production. There is no hope that they can supply our energy needs. The only practical substitute for fossil fuels is nuclear power. In 1988 some 1.9×10^{12} kWh of electricity was generated by nuclear power stations. The same amount would be produced by burning 900 million tonnes of coal or 600 million tonnes of oil. In other words, the emission of 3000 million tonnes of carbon dioxide has been saved by using nuclear power, rather than coal. (While coal emits 850 tonnes of carbon dioxide per gigawatt hour, the figures for oil are 750, gas 500, nuclear 8, wind 7 and hydro 4.)

As countries switch to nuclear, their rate of carbon-dioxide emissions fall. Since 1970 France has halved its emissions, Japan (32% nuclear) has achieved a reduction of 20%, while the US (20% nuclear) has reduced it by only 6%. The emission of noxious gases like sulphur dioxide is also dramatically reduced by going nuclear.

The UK government, meanwhile, wants its emissions of greenhouse gases to be 10% lower by 2010 than they were in 1990. A reduction of 6% had been achieved by 1995, which was due to nuclear-power output rising by 39% between 1990 and 1994. However, if no more nuclear power stations are built, the level of emissions will rise steeply. In subsequent years, as older nuclear power stations are decommissioned, the UK will find it impossible to reach its target.

Although many new gas-fired power stations, which emit only half as much carbon dioxide as coal-fired power stations, are currently being built, the problem is that they leak methane, which has a "global-warming potential" of about 60 times that of carbon dioxide. These two effects approximately balance out, which means that we can expect no reduction in global warming by switching from coal to gas. Even if this methane effect is neglected, then if gas increases to 43.5% of total production, while coal declines to 2.5%, we can expect carbon-dioxide emissions to fall by 10%. And if nuclear rises to 43.5% at the expense of coal there will be a 20% fall.

If we do not solve the world's energy problems now, then they will soon be solved for us. We are living in a special period in human history when oil, gas and coal are readily available. At present rates of consumption, the oil and gas will be gone in less than 100 years, and coal in about 200–300 years. Fossil-fuel burning will then cease and alternatives will have to be found. If we continue to burn fossil fuels, we not only pollute the Earth and initiate global warming, we also deprive future generations of these valuable materials, the bases of petrochemical industries. Would it not be better to solve these problems now – using nuclear power – instead of waiting until it is too late?

NO

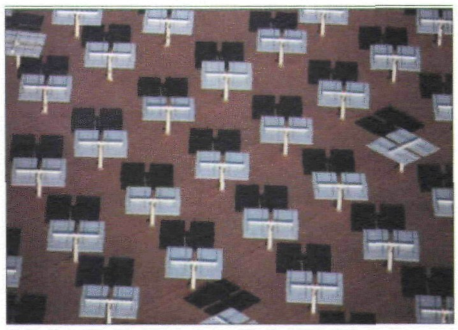
I disagree with Hodgson that "the only practical substitute for fossil fuels is nuclear power". The alternative of renewable energy is abundant, as he points out, but its *practical* potential is also far greater than he suggests. It could, in theory, meet *all* of the world's energy demands. In practice, we will end up with a mix of energy supplies. Hydrogen production from coal-bed methane and natural gas is a promising option, for example (the CO_2 by-product being used for the enhanced recovery of oil or coal-bed methane on a non-net-carbon-emitting cycle). This is not merely my view: the IPCC, in all three of its assessment reports, has arrived at the same conclusion, as have many industrial and academic studies.

First two myths about renewable energy need to be dispelled. One is that it is too dispersed to be of practical use without despoiling the landscape. Over vast areas of the developing world, the incident solar energy is 2000–2700 kWh per square metre of ground occupied per year. Solar-thermal power stations can convert more than 20% of this to electricity, and photovoltaics now on the market about 15% of it. This is more than two orders of magnitude higher than the energy produced by common crops and wood from an equivalent area of land. All of the world's future energy demands could, in theory, be met by solar devices occupying about:

- 1% of the land now used for crops and pasture; or
- the same area of land currently inundated by hydroelectric schemes, the electricity yield per unit area of solar technologies being 50–100 times that of an average hydro scheme.

A sizeable portion of energy supplies could also be produced by roof-top solar devices. Nor should we overlook resources such as biomass (which could enable vast areas of degraded land in developing countries to be restored), as well as offshore wind, geothermal energy and the energy in tidal streams and waves. Although I share Hodgson's concerns about the dangers of wind turbines despoiling the landscape, they are now being installed offshore. Multi-sourced systems based on wind, waves, tidal streams and solar power are also possible. Solar schemes are also architecturally attractive.

The second myth is that renewable energy (other than biomass) cannot be stored. A range of options is now being developed, including thermal, mechanical, thermo-



Practical challenge – solar devices could, in theory, meet all of the world's future energy demands

chemical and electrochemical storage, as well as the production and storage of hydrogen for fuel cells or direct combustion for both stationary applications and transport. Even nuclear power needs to solve its "storage problem", both to service peak loads on electricity systems and to meet the immense energy needs of transport.

Producing hydrogen from solar photovoltaics and wind power is estimated to cost between £0.05–0.10 per kilowatt hour, roughly 7–15 times the cost of natural gas. However, the costs could decline fivefold with economies of scale and as the manufacture of electrolysers develops (see Ogden in further reading). And although nuclear power has the economic advantage of using the capacity of electrolysers more fully, the long-term average costs of renewables are as low as – if not lower than – those of nuclear power. Renewable-energy–hydrogen systems are unlikely to cost more than nuclear–hydrogen systems – and possibly less.

The costs of renewable-energy technologies differ greatly with location. Solar technologies are more economical in the sun-drenched tropics, where seasonal variations in sun levels are lower than in other regions of the world and solar peaks match demand peaks much better. In fact, solar technologies are over five times cheaper per kilowatt-hour for most developing nations. What might look a distinctly unpromising technology to a pessimist on a rainy day in northern Europe is highly promising where 5 billion of the world's population live, and where energy demands are growing fastest.

There is already a rapidly growing market in the developing world for applications that use the Sun for water pumping, lighting and health clinics, and as a back-up for grid supplies and to supplement peak loads. Solar applications also avoid the capital expenditures on – and losses in – transmitting and distributing electricity, which account for about 50% of the costs of electricity supply in urban areas and over 75% in rural areas and towns. Fuel cells as decentralized sources of electricity generation – using hydrogen generated from renewable energy – would give rise to similar savings and, in colder climates, would be an efficient source of combined heat and power.

All of these renewable technologies are proven options and are fertile areas for R&D; the literature is notable for the range of advances that are being reported, not least in conversion efficiencies. They are still in an early phase of development, significant efforts having begun barely two decades ago. The technologies are modular and well suited for batch production. The lead times are just a few months, compared to 7–10 years for nuclear reactors and 3–5 years for fossil-fuel power stations. This is an important source of cost savings and allows the technologies to be developed quickly. They can also be decommissioned and the materials recycled relatively easily.

Such factors will not, of course, guarantee economic success, and it will be important to develop economically viable storage systems, including the fuel-cell–hydrogen option. But they do suggest that we have energy sources of immense promise if we are prepared to support them through wise policies.

It is hard to overstate the size of the task if we are to replace fossil fuels by renewable or nuclear energy to mitigate the effects of climate change. According to the IPCC and the World Energy Assessment – which was carried out last year by the UN Development Programme and the World Energy Council – global primary-energy demands will rise from about 400×10^{18} J today to 800–1600×10^{18} J by the end of the 21st century, depending on assumptions about energy efficiency. This is equivalent to the output of 15–30 million MW of nuclear power.

Given the huge problems of decommissioning and waste disposal, the share of nuclear power in meeting future energy needs is bound to be limited. We cannot rely on nuclear power to solve the climate-change problem. We should therefore develop ways of using solar power – the one safe and abundant form of fusion energy that is already available to us in perpetuity. I appreciate how far developments in renewable energy and hydrogen-powered fuel cells have to go, the difficulties and risks of developing an industry from a small base, and the time it will take to switch from fossil fuels. But we must explore and develop these options.

YES

Meeting the world's energy needs is an urgent problem – and all practicable energy sources must be used to solve it. The exact mix in different regions will depend on many factors, particularly the indigenous fuels as well as local geography and economics. Developed countries must help developing nations to increase their energy supplies and curb existing wasteful habits. Continuing efforts must be made to reduce pollution and carbon-dioxide emissions. To make progress in discussions about energy production and the effects on the environment, it is essential to have numerical data. Without such information, it is impossible to know whether a proposed source or effect is important or negligible.

If we are to stabilize the emission of carbon dioxide by the middle of the 21st century, we need to replace 2000 fossil-fuel power stations in the next 40 years, equivalent to a rate of one per week. Can we find 500 km^2 each week to install 4000 windmills? Or perhaps we could cover 10 km^2 of desert each week with solar panels and keep them clean? Tidal power can produce large amounts of energy, but can we find a new Severn estuary and build a barrage costing £9bn every five weeks?

Nuclear power, however, is a well tried and reliable source, whereas the alternatives listed by Anderson are mainly hope for the future and have yet to prove themselves. At the height of new nuclear construction in the 1980s, an average of 23 new nuclear reactors were being built each year, with a peak of 43 in 1983. A construction rate of one per week is therefore practicable.

I hold no special brief for nuclear power. If there were another way of providing our energy needs without destroying the Earth, I would support it. I am not, I must admit, happy about the dangers of nuclear radiation. I know that, in the hands of engineers at, say, Sizewell, nuclear power is extremely safe, but I can think of many places that would not inspire me with the same confidence. There is always the fallibility of human nature, and the danger that politics will domineer engineering prudence, although the same could be said of all modern technology. Strict controls and eternal vigilance are therefore the price we must pay for its benefits.

A careful and objective analysis will reveal the best energy policies to adopt. It is all too likely, however, that this will not coincide with public views. This puts governments in a dilemma; they can remain popular only by adopting policies that they know are not the best ones from an objective scientific viewpoint. Methods of tackling this serious and intractable problem will have to be discussed.

So do we need nuclear power? Obviously not, if all we care about is having enough energy for the next 100–200 years to continue our current wasteful lifestyles. But then we must pay the price in terms of pollution: sterile lakes and dying forests, climate change and the international tensions generated by the scramble for the last remaining oil. To avoid these consequences, such fuels must be replaced by non-polluting sources, and the only realistic possibility is nuclear power. If we care for the Earth, then, like it or lump it, we need nuclear power.

NO

I believe industrialized nations should adopt a modest carbon tax with the revenues being earmarked for R&D and tax incentives to commercialize the following technologies:

- offshore renewable-energy resources;
- hydrogen systems and fuel cells;
- photovoltaics;
- advanced energy-storage systems, including hydrogen storage;
- geothermal energy; and
- improved energy efficiency, including small-scale systems that combine both heat and power.

The end is nigh – despite advances in exploration and production, fossil fuels will eventually run out

Although industrial countries, including the UK, are already heading in these directions, their policies are minuscule in comparison with the effort they expended on nuclear power in the past.

Developing countries also need to initiate parallel programmes. Building on the work of the UN Framework Conventions on climate change and biodiversity, these programmes should – in addition to the above policies – include the development of advanced solar-thermal power stations and multi-purpose schemes for the sustainable production of biomass for energy use and the restoration of degraded lands and watersheds.

It is *precisely because* renewable energy still accounts for such a small share of output, coupled with its promise, that these programmes are justified from both an economic and an environmental perspective. When promising technologies are emerging, they need to be nurtured and researched more fully, to see what they will yield. Of all the arguments against renewable energy, the one that it still accounts for only a small fraction of output relative to nuclear power is the worst. Nuclear power generated little in the 1950s; but that did not stop governments subsidizing the industry to the tune of $0.5–1 trillion over the following 40 years. In the early phases of a technology, there is more to be discovered, more scope for progress, more scope for reducing costs through invention and innovation, and economies of scale are more marked. The costs of photovoltaic modules, for example, fell from $300 000 per kilowatt in the 1970s to $3000 per kilowatt by the late 1990s, and the scope for further reductions is far from exhausted.

The "learning curves" for renewable-energy technologies are steep, the unit costs falling by 15%–25% every time the cumulative volume of production doubles. There is every indication that fuel cells and hydrogen production will decline in cost at a similar rate, provided that we invest in their development. Indeed, over 5 GW of new renewable-energy capacity is already being installed each year, and markets are doubling every 3–4 years. If their share in energy production rose to 5%–10% of world energy supplies, their costs would decline by three- to fivefold. At worst, we would have an important source of energy supplies; at best, a proven way of meeting the world's energy needs in perpetuity without carbon emissions, and a cheaper and abundant source of energy – most of all in developing nations.

As for nuclear power, it should be exempted from carbon taxes and climate-change levies. To put a carbon tax on non-carbon energy sources is illogical and inappropriate. The huge legacy of nuclear waste and the decommissioning of old nuclear plants must also be addressed by public policies. Beyond that, the nuclear industry is now surely mature enough to stand on its own feet. It does not merit further public financial support, which would be better used for other purposes. It should put the case for new plant to the financial markets, not to governments, and in doing so make the necessary provisions for meeting the costs of waste disposal and eventual decommissioning.

Further reading

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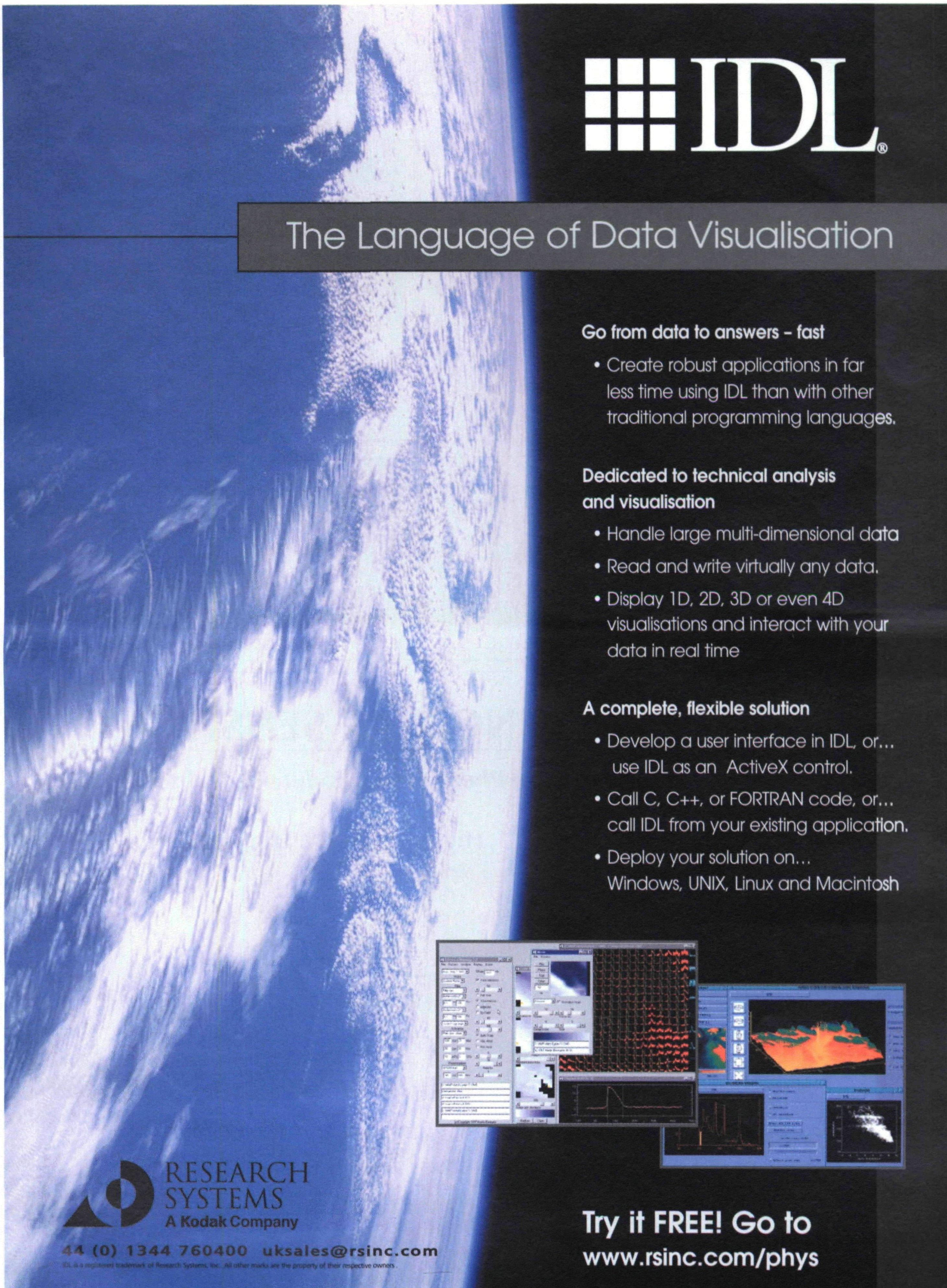
Peter Hodgson is a nuclear physicist at Oxford University and has been active in the field since 1948. He has written extensively on the influence of nuclear physics on society and served on the council of the Atomic Scientists Association, e-mail p.hodgson1@physics.oxford.ac.uk **Dennis Anderson** is director of the Centre for Energy Policy and Technology, Imperial College, London, former chief economist to the Royal Dutch Shell Group and former economist and energy adviser to the World Bank, e-mail dennis.anderson@ic.ac.uk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