of energy because of their place in the financial community's commitments to the 'Equator Principles', in major international companies' commitments to the UN Secretary-General's 'Global Compact', and in processes such as the World Bank's Extractive Industries Review.

'Energy Security' is ambiguous. In today's competitive domestic energy markets it means continuity of supply for final consumers. In the gas and electricity sectors, there can be disruptions which no price can cure in the short term. A 'liberalised' market structure does not reward the carrying of strategic inventories or spare capacity. The risk of such domestic disruptions has been shifted to consumers.

In the 1970s, 'Energy security' meant security of imports from political disruption, and this concept is still invoked, though since 1973 all political sanctions on energy have been imposed by importers, such as the USA, on exporters, such as Iran, Libya, Iraq, Sudan, Myanmar, and so on. These demonstrate that energy sanctions are important only where there is a wider security confrontation. No exporter – even Russia – is in a position to challenge the USA or NATO members militarily, and none can make up for its lack of military and diplomatic power by an oil or gas weapon. The exceptional case is, as in 1973, the vulnerability of Israel and the resulting implication of the United States.

The headline energy policy objectives are not necessarily coherent. 'Reducing import dependence' – the old slogan – has no systematic relationship with the climate change objectives with which the EU and UK policy documents are crammed: domestic energy may emit more or less greenhouse gases than imports. The principle of 'Internalising external costs' gives way to politics in the negotiation of cap-and-trade emissions allocations in the EU, in energy taxes which are not related to emissions – and in most European taxes on transport fuel.

Most OECD current energy policies avoid hard conclusions on nuclear energy with its environmental benefits, and risks, uncertain standard economics, and links to proliferation and military issues.

So what to do? The first step is to think more clearly. We should unpack the old suitcase of energy policy, sift out the clichés, the green packaging, and the special pleading, and connect the real objectives with their drivers outside the energy sector. Energy security should be deconstructed into reliability at the last stage before the consumer – mainly a local issue; reliability and diversity of international infrastructures; and genuine national security and foreign policy issues.

Tracking policies to their sources would not diminish the responsibility of energy ministries, energy producing and consuming enterprises and energy experts for integrating the policies and reconciling them with technical and economic realities.

The next step would be to recognise the broad nature of energy governance, to connect more clearly with

- The developing international relationships between the OECD, the developing countries, and the petroleum exporters, not just in the WTO, which most petroleum exporters have now joined or are seeking to join, but in the growing networks of bilateral and regional agreements and in global negotiations on climate policy and sustainable development.
- The inter-sectoral efforts to develop sustainable technologies of consumption. These directly involve business – and not only energy businesses. Examples are the European Commission's auto-oil programme (now copied in China and India), the US and IEA support of R&D for relevant technologies, and the 'Mobility' initiative of the World Business Council for Sustainable Development. Business involvement can make frontiers and sector boundaries easier to cross than can government bureaucracies.
- The need for continual acceptance and re-acceptance by civil society of the energy production and consumption activities. The nuclear question is central to this.

The old energy policy portmanteau was carried along by the slowly changing dependence of economic growth on increasing energy consumption and the consequent need for supply. Neither the natural resources nor the natural environment of the world can sustain this path of growth as the numbers projected for China and India take effect.

A new approach to energy governance requires a different coordinating principle. Government commitments to Sustainable Development are wordy, vague, and often contradictory, but are much more far-reaching than the traditional exhortations for 'win-win' energy efficiency or the emission reduction targets of the Kyoto Protocol. The connections between transport and economic development, and between electrification and economic development, have to be rethought and then reformed to enable human welfare to grow without unacceptable damage to the natural environment and the interests of future generations by the consumption and production of energy.

Technology and Energy – 21st Century Outlook

Bernard J. Bulkin

For the past 150 years of energy production and consumption, technology has always exceeded our expectations. Sure, there have been some things that were speculated on thirty years ago as coming soon, and which have still not appeared, but this is probably less a failure of technology development than of speculation. And there is very little reason to believe that the next 150 years will be any different.

This paper will talk in more detail about various primary energy sources, and their technological prospects, and several aspects of demand for energy, where new technology can have an impact. Broadly, there are four things driving change in energy technology:

- Environment – growing worldwide concern about climate change, continuing concerns about local air, water, and land quality, and regulatory pressures on all of these areas. It has been well established by Michael Porter and Claas Van Der Linde that if one sets the regulatory bar high, and leaves sufficient time to comply, then new technology will come to market allowing compliance with high standards at much lower cost than anticipated.
- Price – the sustained period of high oil and gas prices is likely to lead to stronger research budgets across a range of technological problems, as well as making it easier for new technological alternatives to be economically persuasive in the market.
- Security of supply – continuing concerns drive the development of new technology to enable diversification of supply sources, and, for big consumers (USA, China, Japan, India) to enable domestic sources of primary energy to take a bigger share, without compromising environmental standards.
- Cultural change – consumers are changing, and demanding that companies respond to their expectations on environment, price, and choice. New technologies will be developed to allow companies to win market share.

Now it has to be said that not everyone agrees with this optimistic outlook for technology. Mayer Hillman, a leading UK thinker on energy and environment, has taken a very opposite view in a recent book, *How We Can Save the Planet.* He argues that 'technology is highly unlikely to be able to reduce carbon dioxide emissions sufficiently… to avoid serious damage to the planet'. Rather, he argues, 'Major changes to our lifestyles will be necessary'. He goes on to argue that in the UK the average household must, over the next fifty years, reduce its CO_2 emissions through lifestyle changes to below 20% of today's level. His chapter on the role of technology he calls 'Wishful Thinking'. Hillman looks at the three broad areas of energy efficiency, less carbon intensive or zero carbon energy sources, and carbon capture and sequestration, asking whether they can collectively make sufficient impact. His arguments are flawed in that they really try to show that any one of the individual technologies will not solve the problem, from which he argues that they cannot solve the problem in aggregate either.

A much more sophisticated approach has been put forward in a recent paper by Steven Pacala and Robert Socolow, accepting that no one thing will solve the carbon problem, but that there are possibilities for half a dozen big things to make sufficient impact.

"we can expect order of magnitude improvements in the ratio of efficiency/cost for photovoltaics"

Before looking to the future, it is worth highlighting a few fairly recent responses to signals similar to those we are seeing today. Between 1973 and 1980 the fuel economy of the car fleets in the USA and Europe approximately doubled. And while there has been some loss of fuel economy in recent years because of increased sale of light trucks, most of the gains are still with us thirty years later. Moreover, to meet the demand for improved urban air quality, technology in fuels, combustion, engine management, and after-treatment has reduced emissions by 99% over the same period, and further reductions will occur in the next few years. While we might have anticipated some of these, the impact of the development and application of information technology to vehicles has gone far beyond anyone's speculation.

White goods have become much more efficient. A study by the US Department of Energy showed that the energy efficiency of refrigerators has increased by 300% in the past thirty years. Coupled with better labelling, this has led to major changes in consumer purchasing behaviour. As a result, all manufacturers have been forced to come up to the higher standard.

And further up the chain, the progress in finding oil and gas, and in producing it more cheaply, has been spectacular. As a result of technology such as horizontal drilling and multilateral wells, oil fields that were uneconomic at $30 per barrel when discovered 25 years ago are now being produced with good returns at prices above $14 per barrel. This is all due to technological advances that were unanticipated.

So let's look ahead. It is not possible to consider every aspect of energy technology here, but I want to focus on a few that are likely to be most important, and in some cases, most controversial. Starting with supply.

There is every reason to believe that there will be continuing progress in oil and gas production. While the theme of the coming decades is likely to be more about recovery than discovery, and about utilisation of non-conventional oil, there is a lot of technological stretch left in this old game. The integration of surface and sub-surface technologies around aggressive use of information technology has the potential for a step change in recovery.

Gas to liquids technology has made impressive gains in the past decade, and there is more to come. For those bringing gas to market GTL competes with pipelines and LNG, though its product(s) serve different needs. We may be at a tipping point for GTL, after many years of effort, where the first world-scale plants using new technology come on stream in the next few years. If high oil prices are sustained, and the corresponding cost of isolated gas does not rise as fast as gas that has easy markets, economics will begin to favour GTL, and producers will see this opportunity as comparable in risk to LNG or pipelines.

Another interesting technological

alternative for gas is 'gas by wire', in which electricity is generated at the wellhead, transmitted to population centres as high voltage DC, and the carbon emissions from the power generation are sequestered at the source. We can expect to see this used in cases where building a pipeline is expensive, environmentally sensitive, or dangerous. Of course, putting a price on carbon would make a big difference to the viability of gas by wire.

Nuclear is also interesting technologically. Today in most circumstances nuclear is too expensive, and the concerns about long lived radioactive waste too serious. Still, new plants are being built, perhaps as many as thirty will commission in the next five years. More importantly, research on a variety of nuclear technologies is proceeding, and fast reactors, hybrid fission/fusion technologies, and other ways of dealing with the waste problem using novel materials all mean that our view of nuclear power may be very different in the next decade.

Now let us turn to renewables. I have already commented on this elsewhere and will just recapitulate the arguments here. Briefly, not all of these are the same in terms of their prospects. If we look at the various renewable energy sources from the viewpoint of possible technological advance, they look very different. For example, wave and tidal power are fairly low tech. Certainly there have been some advances in engineering design to lower cost and improve efficiency, but these have not yielded a competitive technology. And there is no gain that can be foreseen from mass manufacturing. Wind turbines may have some technical stretch left from applying new materials and information technology to control the turbines, all to help at high wind speeds, but again we are talking about less than 25% incremental improvement from where we are today.

Contrast this with the situation for solar photovoltaics and for biomass. Solar PV is an application of materials science, where there is a lot of action today. Novel electronic materials are being developed, and we can expect order of magnitude improvements in the ratio of efficiency/cost for photovoltaics. Will we get to PV devices that can be painted on to roofs, and cost little more than paint? Don't know, but it is a reasonable research goal.

Biomass utilisation for energy is even more prospective. Low cost feedstocks, especially cellulosic feedstocks, are waste products today that could become fuels, speciality chemicals, and primary energy tomorrow. We should expect that biotechnology will deliver improvements in cost of several orders of magnitude. Moreover, new processes will be able to be scaled up quickly, because the process engineering is not difficult.

So there are prospects for renewables, not everywhere but in some important areas.

Now let's look briefly at some of the possibilities on the demand side. Road transport is the easiest place to start, because technology already exists to double the fuel economy of the fleet, without infrastructure change. Hybrid vehicles are already on the market, and while they are only a small fraction of today's fleet, this will change in the coming decade. But most important is that today's hybrid vehicle is only the beginning of what is possible, and we can expect to see ever more dramatic improvement in fuel economy from this technology. It is applicable across the full range of vehicles, requires no infrastructure change, carries only a small cost penalty, and is attractive to consumers at high oil prices.

Fuel cells and hydrogen for transport and stationary power should be the subject of a whole paper in themselves. This technology may make sense, and may achieve all that it needs to achieve in order to be widely accepted, but the jury is still out. What we can say is that the massive research and technology development expenditure in this area will lead to a diverse set of impacts, most of which we cannot yet anticipate. Today's hybrid vehicles use a lot of technology that was developed for failed projects in pure electric vehicles, and we can expect the same thing from the fuel cell effort.

What about domestic efficiency? Sooner or later consumers will wake up to the increasing portion of their electricity bill that is just for appliances on standby (maybe 15% on average already in the UK), and demand changes to how these appliances are made. A technological response is certainly possible to meet this requirement.

That will effectively slow or even stop the growth in electricity demand in the older EU, depending on how fast the number of households grows. The big unknown is the demand for air conditioning. We cannot meet climate change targets for reduction in emissions and air condition all of Europe, unless a radically more efficient form of air conditioning is developed. This will have to be based around combustion and heat pumps.

There are many other technological responses possible for homes, office buildings, and agriculture, and it is not possible to enumerate either the problems or the potential solutions here.

There is one other aspect of importance to a look ahead on energy technology. We have come to think of the USA and the EU as the sources of new technology for the world. The coming decade will show that this is not the case. A lot of the new technology we will be using to meet our energy supply and demand beyond 2010 will come from China, from India, other Asian countries, Russia, perhaps from Brazil or places we have not thought of yet. But certainly China will be a major exporter of new technology, as well as a major user. A more diverse group of creative people working on these big problems must mean that we will have a greater diversity of solutions.

This is a time for great optimism about energy technology. We should expect a lot, and assume that our expectations will again be exceeded.