COVER: Masked against noxious emissions, workers cycle home from China’s state-owned Baotou steelworks in Inner Mongolia

PHOTOGRAPH: Natalie Behring/Panos
THIS SPECIAL ISSUE OF OPTIMA, published to coincide with Anglo American’s 3rd annual Energy Day, brings together an illustrious range of contributors in the energy field.

Optima opens with an article by the President of Britain’s Royal Society and Astronomer Royal Martin Rees, who puts the case for a ‘son of Kyoto’ agreement to take us beyond 2012, stressing the importance of public-sector research and development funding for technologies that currently are too far from market. Daniel Litvin, director of Critical Resource and author of Empires of Profit: Commerce, Conquest and Corporate Responsibility, shows how collaboration and far-sighted leadership are needed on the part of governments and the private sector if there is to be a positive outcome to the growing tensions surrounding issues of energy security. Tony Juniper, an executive director at Friends of the Earth, provides an NGO perspective on the climate-change and energy-security challenges that stand in the way of what he would see as a cleaner, more sustainable and secure future. The importance of – much cleaner – coal as a key component of any future energy mix is the topic covered by Milton Catelin, chief executive of the World Coal Institute. Against a background of inexorable energy-demand growth and growing worries of greenhouse gas emissions from fossil fuels, MIT professors John Deutch and Ernest Moniz examine the possibilities of the ‘carbon-free’ nuclear option. Finally, Professor of Energy at the University of California, Berkeley, Daniel Kammen looks at the prospects in advancing the development and commercialisation of renewable energy resources.

Complementing this distinguished cast of authors, there are contributions from Anglo American’s own specialists in the energy field. These contributions include Anglo American’s widening range of energy partnerships; accounts of the energy-supply and climate-change policy scenarios developed at an internal workshop; and the initiatives the Group is taking to reduce its unit energy consumption and carbon footprint by becoming more energy-efficient. ◆
Improving energy efficiency is an attractive option in curbing energy demand growth in that it is the cheapest and an environmentally sound form of cost and risk mitigation – and it is open to us right now. But it will only take us so far. Global demand for energy is almost 50% higher than it was 20 years ago, and the International Energy Agency sees energy demand, largely driven by the burgeoning economies of the developing world, increasing by more than half over the next 25 years. That implies that all known sources of energy will be required to meet this demand.

Fossil fuels – oil, gas and coal, which still supply around 80% of the world’s energy – are likely to continue to power the global economy until at least mid-century. Even if published oil reserves do cover only some 40 years of current consumption, there are substantial reserves of gas and coal. But, today, more than half of the world’s oil is being supplied through international trade, illustrating the high level of geographical mismatch between sources of supply and demand. Yet “Old King Coal”, the fuel that started the Industrial Revolution, and the fossil fuel least beset by the anxieties surrounding ‘resource nationalism’, looks set for a renewed lease of life as the world’s most abundant, affordable and secure fuel source – if only its carbon impacts can be tamed. Currently, 50% of the US’s electricity, 80% of China’s and 70% of India’s electricity is generated from coal, most of it from their own domestic resources, while China is starting up a coal-fired power station every few days and the US has 150 new coal-fired power plants on the drawing-board.

All of this, of course, comes at a cost. In a summary of its Fourth Assessment Report, due for publication this year, the Intergovernmental Panel on Climate Change (IPCC) assembles clear scientific evidence from many sources of the impact of human-induced climate change caused by the emissions of CO₂ and other greenhouse gases (GHGs) that have accumulated in the atmosphere over the past century. Even the lower end of the IPCC’s scenario shows CO₂ concentration levels rising from 380 parts per million (ppm) today to 550 ppm, raising temperatures by 2°C by the end of the century. Moreover, the IPCC estimates that the largest growth in GHG emissions has come from the energy-supply sector, with an increase of 145% between 1970 and 2004.

The good news is that measures can be taken to avert some of the worse effects of climate change. But we need to act now. The Economics of Climate Change: The Stern Review, published late last year in the UK, has demonstrated that early investment could significantly reduce the overall economic costs of the impacts of climate change – and that prompt, strong and internationally co-ordinated action on climate change is needed. As Martin Rees emphasises in his article, “We need a ‘son of Kyoto’
That is why Anglo American is engaged in research with various partners on integrated CCS projects. According to sources like the IPCC and Princeton’s Robert Socolow, CCS could provide a significant percentage of the world’s total effort to reduce emissions in the medium term. In Australia, Anglo American is involved with Shell in the Monash brown-coal-to-liquids project, which envisions the sequestration of CO$_2$ offshore in the deep subsurface structures of the Bass Strait. Also in Australia, Anglo Coal has been capturing methane gas from underground workings and selling it to a power station to generate electricity, as well as to Queensland State Gas’s pipeline grid, achieving greenhouse gas savings equivalent to taking 375,000 cars off the road. Since early last year, Anglo American has also been a member of the FutureGen Industrial Alliance. Co-operating with the US Department of Energy, this is a public-private partnership the purpose of which is to design, construct and operate the world’s first commercial-scale, near-zero-emission power-generation plant that produces electricity and hydrogen from coal while sequestering CO$_2$.

Forecasting longer term in energy development is notoriously difficult – not least because technologies will not remain unchanged. Much will depend, though, on technology’s ability to get the economics of CCS commercialisation right – and on initiatives such as government taxes on carbon on the one hand, and cap-and-trade market mechanisms on the other. Persuading developed countries, let alone developing ones, to create a carbon price will be extremely difficult. Business will have to encourage and then support governments in the implementation of necessary rational frameworks. Outside the fossil-fuels area, nuclear will almost certainly enjoy a renaissance as demand for clean energy grows and the industry’s costs come down. Renewables, despite their generally high abatement costs, are currently providing 13% of the world’s energy needs and will grow in importance, attracting growing amounts of Silicon Valley-type capital. And energy efficiency – the one ‘easy’ option that is open to us all – will be pursued with vigour.

Perhaps the final word should rest with the Financial Times’s Martin Wolf, who observed recently that: “The world can afford quite expensive energy. The big question is whether the environment on which our lives depend can cope with the results.”

Sir Mark Moody-Stuart is chairman of Anglo American plc
Indeed, in February this year the Intergovernmental Panel on Climate Change (IPCC) published the first volume of Climate Change 2007, The Physical Science Basis – a comprehensive picture of the latest scientific understanding on the issue. This report was produced by some 600 authors from 40 countries and assesses the current scientific knowledge of the natural and human drivers of climate change, observed changes in climate, the ability of science to attribute changes to different causes, and projections for future climate change.

The report concludes that warming of the climate system is unequivocal, as evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global sea levels. It says that it is “very likely” – or that there is at least a 90% chance – that human emissions of greenhouse gases (GHGs), rather than natural factors, are the major cause of this global climate change.

Because of the fossil fuels already burnt, there is more carbon dioxide (CO₂) in the atmosphere than there has been for at least half a million years – perhaps even the last 20 million years. Moreover, the global economy is generating CO₂ at an accelerating rate. These uncontroversial facts, combined with simple ideas on greenhouse warming dating back to Tyndall¹ and Arrhenius², should in themselves motivate deep concern, but of course the science has firmed up immensely.

Urgent action must be taken if we are to avert a global energy crisis.

Beyond Kyoto

Martin Rees
Furthermore, because of time lags in the climate system, even if we could keep atmospheric levels of GHGs constant at today's level by drastically reducing emissions, we would continue to see further global warming and rises in sea levels. And we will have to learn how to live with the changes these bring.

This report has underscored, yet again, that the scientific understanding of climate change is sufficiently clear to justify nations taking urgent action – both to cut GHG emissions into the atmosphere and adapt to its impacts.

And it is not just science that speaks to the urgency of action. Sir Nicholas Stern, former Chief Economist at the World Bank, in his review of the economics of climate change estimated that, on the basis of formal economic models, if we don't act, the overall costs and risk of climate change will be equivalent to losing at least 5% of global GDP each year, now and forever. If the wider range of risks and impacts is taken into account, the estimates of damage could rise to 20% of GDP or more.

Stern argues that justice to future generations – plus the possibility that ‘business as usual' could itself lead to climate change so drastic that it chokes economic growth – justifies adopting a low discount rate, and committing substantial resources to cutting GHG emissions now rather than later. (There are other contexts where non-commercial discount rates are applied. Indeed, in discussing nuclear-waste disposal, people talk with a straight face about what might happen more than 10,000 years from now – thereby implicitly applying a zero discount rate.)

In our reaction to impending climate change, to quote US Vice President in the Clinton administration Al Gore, “We must not leap from denial to despair. We can do something and we must.” Yet, notwithstanding the ratification of the Kyoto Protocol – which commits countries to international targets on reducing emissions of GHGs – we are still just coming out of the starting blocks in our efforts to tackle climate change.

At an international level, the leadership that the developed countries should be showing has been impeded by the dispute over whether there should be legally-binding national targets. Such arguments have caused the world to lose sight of what should be the most important objective of policies on GHGs, namely to stabilise their concentrations in the atmosphere at a level that avoids an unacceptable risk of ‘dangerous' climate change.

The United Nations Framework Convention on Climate Change – which underpins the Kyoto Protocol – commits the international community to ‘stabilisation of GHG concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system'. However, the convention does not define ‘dangerous anthropogenic interference’ or exactly at what concentration GHGs should be stabilised. These definitions are crucial to inform the level of action, including emissions reductions, that is required. They must be informed by science, but at their very heart are questions concerning what effects of climate change the international community deems politically, socially and economically unacceptable.

We need a ‘son of Kyoto' agreement that takes us beyond 2012, the first commitment period of the Kyoto Protocol, that rallies international action, involving developed and developing nations, to meet an appropriate and ambitious stabilisation target informed by these definitions.
Any such target must remain flexible, with the potential to be amended if necessary, as science reduces the uncertainties.

And to meet the challenge of reducing the levels of GHGs in the atmosphere, we must be promoting and investing in renewable energies as well as improving energy efficiency, managing demand better and exploring new technologies such as ‘clean’ coal and carbon capture and storage (CCS). Irrespective of climate change, these would be beneficial in enhancing energy security.

Replacing the traditional coal, oil and gas that now supply around 80% of the world’s growing energy needs is an immense challenge. This will require appropriate policies and economic instruments to promote energy efficiency and to incentivise clean fossil-fuel, nuclear and renewable technologies.

There should be, for example, a cost on emissions of CO₂ from all sources, including industry, domestic users and transport, in the form of a ‘carbon tax’ to help encourage investment in low-carbon technologies and move us away from the current system with its reliance on fossil fuels.

Vitaly, we also need to be addressing the serious inadequacy of research and development (R&D) funding and provide incentives to accelerate advanced energy-related R&D, including in partnership with private companies. These concerns were set out in a statement issued by the Royal Society and the science academies of other G8 nations, plus those of China, India, Brazil and South Africa, last year before the G8 summit in St Petersburg.

While the joint communiqué that came out of this G8 summit included many significant commitments, it omitted one crucial pledge: a significant increase in their governments’ investments in R&D for energy technologies. This omission reflects a worrisome lack of determination to accelerate the development of new energy technologies. The urgent challenge is to meet global demand (scheduled to rise by more than 50% in the next 25 years according to the International Energy Agency (IEA)) while reducing the impact of GHGs on climate change.

The St Petersburg communiqué provided a list of future actions focused on private-sector energy funding, but neglected to emphasise the importance of public-sector R&D funding for those technologies too far from market. It is perhaps not surprising that the communiqué had little to say on government R&D expenditure. A recent paper published by Paul Runci concluded that public-sector R&D investment in energy in most industrialised countries has fallen sharply in real terms from peak levels in the early 1980s, with some stabilisation in the 1990s. That analysis demonstrated that the 11 IEA countries accounting for most of the world’s energy R&D had all decreased expenditures as a proportion of gross domestic product between 1975 and 2003. Investments in major energy R&D programme areas dropped by 53% between 1990 and 2003; fossil fuels and nuclear power accounted for more than 90% of the aggregate decline, but there was also an overall drop of 5% for renewable technologies.

Analysis of these R&D budgets does not tell the whole story, but it does demonstrate that industrial-country governments are not facing up to the huge energy challenges that lie ahead. That is worrisome because the IEA is predicting that by 2030, based on current national policies, 80% of the world’s primary energy demand will be met by fossil fuels. Meanwhile nuclear, hydro, biomass and waste will provide 17% and other renewables, such as geothermal, solar and wind energy will only account for less than 2%.

As a result, the IEA projects that annual energy-related emissions of CO₂ will be 52% higher in 2030 than in 2003. Unless there is a radical change, the world will continue to become more reliant on fossil fuels beyond 2030. Without unfeasibly dramatic breakthroughs in carbon sequestration and energy efficiency, this will lead to proportionate increases in atmospheric GHG concentrations.

The Royal Society is playing its part. Along with the Royal Academy of Engineering it is holding an international workshop on CCS later this year to explore ways to accelerate the development and deployment of these technologies globally. The Society is also currently undertaking a study exploring the research needs for the next generation of biofuels to provide more economic, low-carbon fuel for cars and other forms of transport.
Few of the vaults meet international standards for long-term storage, however, according to the United Nations Food and Agriculture Organization (FAO) which reports that almost one-fifth of its seeds are already degenerating. Hence the creation in 2004 of the Global Crop Diversity Trust, affiliated to the UN, operating from the FAO's offices in Rome, and financed by some 15 national governments, civil-society foundations and the private sector. Interest earned on the money it receives is used to improve the construction and management of seed vaults. Preserving the genetic material of many of the most important food crops merely requires their seed to be kept frozen. That cannot be guaranteed in developing countries where temperatures are often high and electricity supply unreliable. The Trust’s current major project is therefore the co-financing of a seed vault being built on the Norwegian island of Svalbard, close to the North Pole. Despite Svalbard’s ground being permanently frozen, the vault will be built underground, surrounded by rock, and accessed by a 120-metre tunnel. Moreover, it will be located about 130 metres above the current sea level, safe from the expected rise in sea levels caused by global warming melting polar ice.

Concern among scientists over the loss, caused by future climatic changes, of crop diversity and global food security has in recent years led to the establishment of some 1,500 seed vaults around the world. The aim is to preserve the genetic make-up of many thousands of food plants, thereby providing plant breeders with the basic material for developing plant strains that can survive climatic change. Between them the vaults contain over 5 million seeds.

More needs to be done to develop new energy technologies that are currently further from market to deal with rising energy demand and rising GHGs. Governments must play a lead role in stimulating this process by investing more in R&D. One benchmark is set by nuclear fusion, where current publicly funded research runs at around $1.5 billion per year. But fusion is only one of the technologies that are not yet market-ready. Proportionate support of all other options surely would be a prudent investment in a world where the cost of worldwide energy consumption is measured in trillions of dollars. These R&D expenditures could be funded through carbon taxes or similar economic instruments, levied initially across the countries with the largest emissions.

Such a proposal may seem ambitious, but some commentators have argued, with only slight hyperbole, that the energy challenge demands a high-profile response analogous to the Apollo project, but on a global, rather than national, scale. An initiative of this type by world leaders would, as happened after the initiation of the Apollo project in the US, stimulate education and enrolments in science and technology. Might we take heart in US President George W Bush’s apparent turnaround on global warming when he told this year’s G8 summit at Heiligendamm that it is imperative to reduce greenhouse gases and to increase energy efficiency? His statement “I have come here with a strong desire to work on a post-Kyoto agreement” certainly signifies a change of tune on the part of the US. The trick will be to convert this seeming change in sentiment into concrete action.

Banking on seeds

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The vault will have storage capacity for 3 million seed samples — “assisting developing countries by offering a safe haven for their valuable biological material,” says Norway’s Minister of Agriculture and Food, Terje Riis-Johansen.

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1. John Tyndall, a nineteenth-century Irish scientist who realised that gases in the atmosphere cause a greenhouse effect which affects the planet’s temperature
2. Svante Arrhenius, a Swedish chemist who predicted in the late 1890s that emissions from human industry might someday bring about global warming

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Svalbard Global Seed Vault
The answer lies in the soil

Soil is an effective thermal insulator. The temperature two metres below ground level differs noticeably from that of the air immediately above. The deeper one goes, the greater the difference, and the more likely the temperature found there is to remain constant throughout the year.

For the past 50 years or more, systems that utilise that difference have been designed and installed to heat or cool homes and public buildings at an operational cost far lower than using electricity or other forms of energy to thermally change air. The US Department of Energy reports that America’s population of these systems, known as geothermal heat pumps, grows annually by 40,000, encouraged by contributions to their installation costs from utilities companies. Similar subsidies are available in England and Scotland.

The task of these systems is to transfer heat from one place or medium to another that is cooler. Tubing – copper or plastic that rapidly conducts heat – is laid horizontally, in winding fashion, a metre or so below the ground, or is formed into a single U shape that is buried vertically to a far greater depth. The tubing contains a liquid, usually a gas, that is circulated by a pump through the tubing, through the nearby building where a compressor-based system transfers heat to or from the liquid, which is then returned to the subterranean tubing. Meanwhile, the heated or cooled air circulates through ducting.

The system consumes up to 50% less electricity than conventional heating or cooling systems, providing a financial as well as ecological attraction.

Here comes the sun

Electricity produced directly from sunlight was achieved more than 50 years ago when the first photovoltaic cells were developed by Bell Laboratories. The energy of light falling on their core material, silicon, freed electrons in the silicon, and their movement produced electricity. Though silicon is cheap, treating it to encourage electron migration, and then manually assembling it, under exactly controlled conditions, into solar energy-capturing plates makes the technology excessively expensive, except where conventionally generated electricity or a limitless supply of batteries are not available.

There are further disadvantages. Batteries are needed to store the electricity, not a problem for static installations, but irksome when the operations it supports are mobile, such as an army in the field. The cells’ efficiency in converting natural light into electricity is also no better than about 30%. Finally, because the silicon is glass-backed, an assembly of cells has to be flat.

In 1977 it was found that certain plastic polymers allow the movement of electrons through them. Since then various research laboratories have worked on using them in photovoltaic cells. Their manufacture is far cheaper than using silicon. Their flexibility and extreme thinness (a fraction of 1 millimetre) means they can be used to coat a variety of materials and therefore be used on a large or small scale in many different situations, from the jacket one wears to roofing and tents. Recent developments in the field of nanotechnology (devising things on a microscopic scale) is seeing photovoltaic research looking beyond polymers to other substances, and greatly improving light-into-electricity conversion efficiency.

No non-silicon cells are yet being produced commercially, so their promise remains to be proved. Meanwhile, though, the US government, universities and many venture-capital organisations are convinced photovoltaic nanotechnology is the next big wave, and are investing heavily in it.
**A warning on climate change**

“The largest growth in global greenhouse gas (GHG) emissions between 1970 and 2004 has come from the energy-supply sector (an increase of 145%).”

Global warming, caused largely by the developed world’s carbon emissions, will wreak its worst damage on the developing world. That is the conclusion of the Intergovernmental Panel on Climate Change’s working group focusing on the consequences of climate change. It is contained in a summary, released in April, of its report forming part of the IPCC’s *Fourth Assessment Report* due for publication this year.

The summary refutes those arguing that global warming recorded during the past half-century results merely from natural climatic change that has often occurred over millennia. Far more, and better, information about trends in the physical and biological environment and their relationship to regional climatic changes was available for this report than for that published in 2001, says the report, leaving little doubt that man is the culprit.

Damage caused by further warming of 1.5°C-2.5°C is likely to be devastating for the developing world and will eventually seriously tax the resources of the developed world, too. That timing difference is explained by the fact that most of the developing world is located in those parts of the globe where high seasonal temperatures already limit agricultural productivity, stress other environmental systems and habitats, and where there is a lack of resources and skills to mitigate the effects of further warming. In some African countries, drought could halve rain-dependent food production by 2020.

By contrast, agricultural output in the developed world and parts of Asia is likely to benefit initially from global warming of up to 3°C. Higher temperatures are already producing longer growing seasons and higher productivity in temperate latitudes. But once temperatures rise by more than 3°C, many plants will not survive, and the need to adapt agricultural practice – altering cultivars and planting times – will become imperative.

It is not just food and other crop production that will be seriously affected by global warming. So will animal and human habitats and health, in developed as well as developing regions. Indeed, the wide-ranging harm caused by future global warming makes for such alarming reading that it caused the United Nations Security Council, shortly after this report’s publication, to debate climate change for the first time.
The main effects of global warming have already appeared and will worsen. Changes in rainfall levels will produce more storms and floods, but also increase the incidence of drought. Food shortages in the developing world will increase malnutrition and the health problems it produces. Other environmental effects or causes of global warming – ground-level ozone, floods and droughts – will increase the incidence there of diarrhoeal and cardio-respiratory diseases.

People living in higher latitudes, which largely means the developed world, will suffer increased stress as the number of smoggy or high-temperature days occurring annually increases. Diseases and illnesses such as malaria, previously prevalent only in warmer climes, will spread northwards. Heavy rainfall will nurture water-borne disease since it facilitates the migration of pathogens.

Other effects of global warming will be an increase in forest fires, and melting glaciers that put settlements at risk as lakes burst their banks. Melting polar ice will raise global sea levels, imperilling coastal wetlands and mangroves and those dependent on their ecosystems. Coastal flooding could displace millions of people in the developing world, especially those now living in the great deltas of Asia and Africa, in river flood plains and on small islands. In Asia alone, the report estimates, more than 1 billion people will, by 2050, be adversely affected by a combination of potable-water shortage and population growth.

All of which explains the concern about global warming being shown by the European Union. “The effects of climate change,” the report warns, “spread from directly impacted areas to other areas and sectors through extensive and complex linkages.”

The great metaphysical poet John Donne put it better: “No man is an island, entire of itself.”
ENERGY DEMAND IS GROWING – AND AFFORDABLE AND SUSTAINABLE SUPPLIES ARE BECOMING MORE DIFFICULT TO SECURE...

ANGLO AMERICAN’S
ENERGY PARTNERSHIPS

SAMANTHA HOE-RICHARDSON
Higher energy prices are also encouraging the implementation of technologies which are increasing the fungibility of fossil fuels (Fig. 1). Fungibility is the ability to take a wide range of energy sources and convert them into similar, competing products. For example, coal and biomass can be ‘gasified’ through partial combustion in oxygen to create a synthesis gas (or ‘syngas’) comprising carbon monoxide and hydrogen. This can be used for power generation through combustion in the same type of turbine used to generate electricity from natural gas, or supplied into a local gas-supply network for industrial and residential use. The syngas can also be processed further by reacting it with a series of catalysts (this technology is known as Fischer-Tropsch) to produce a range of useful liquids such as diesel, lubricants and methanol or by direct synthesis into dimethyl ether (DME). In all of these cases, emissions of carbon dioxide ($CO_2$) may be mitigated through its capture and storage. If the world were to move towards hydrogen as its main energy carrier (the so-called ‘hydrogen economy’), all of the fuels, along with other non-fossil sources, could be used to generate hydrogen for use in both mobile and stationary applications.

Producing liquids from coal is estimated to be economically viable at oil prices above $35 per barrel. With the oil price averaging around $60 per barrel in 2006 and the International Energy Agency (IEA) forecasting for it to remain around $50 per barrel in real terms until 2030, the conversion of coal into other energy products is, overall, likely to be increasingly attractive. However, the increased volatility of the oil market displayed in recent years is thought unlikely to recede and, with the capital cost of these types of projects running into the billions of dollars, a step-change improvement in their cost is still required.

Anglo American’s market horizons are widening

Anglo American, through Anglo Coal, is not only a leading supplier of carbon to the steel industry in the form of metallurgical coal, but also a major supplier of energy. The increasing fungibility of fossil fuels is broadening the competitive space in which the Group operates, which along with the climate issues associated with coal, is bringing new opportunities, challenges and complexities to its business.

Competitive pressures are intensifying and it is becoming harder for companies to manage the complex environments around them to succeed and to sustain a competitive advantage. In the new knowledge economy connectivity has become one of the key drivers of success. As a result, the barriers between companies are becoming blurred, with companies in one market forming alliances in another. The energy industry is no exception.
New partnerships are being formed in the energy industry

Sasol Chevron was established in October 2000 as a 50:50 joint venture to pursue the commercial application of gas-to-liquids (GTL) technology for selected Chevron- and Sasol-held reserves of natural gas, third-party gas reserves and host countries seeking to monetise their gas reserves. Sasol, the South African petrochemical company, brings what is considered to be the most advanced commercialised Fischer-Tropsch technology to the venture while Chevron, the second largest US-based energy company, offers its capabilities in natural-gas utilisation, product marketing and hydrotreating technology. Sasol Chevron is now constructing a GTL plant in Qatar and exploring opportunities in other countries, including Algeria and Nigeria.

In May 2007, BP and Rio Tinto announced the formation of a new jointly-owned company, Hydrogen Energy, which will develop decarbonised energy projects around the world. The venture will initially focus on hydrogen-fuelled power generation, using fossil fuels and carbon capture and storage (CCS) technology to produce new large-scale supplies of clean electricity. Tony Hayward, BP group chief executive, said: “Projects such as these have the potential to help deliver the carbon-emission reductions which companies and countries around the world are now seeking. This will only be possible if companies work together and work alongside governments. The combination of skills and experience which BP and Rio Tinto bring will allow us to accelerate the development and deployment of these important new technologies and projects.” BP had already been partnering with utilities in two hydrogen power projects with CCS in Scotland and California in the US and these projects will become part of Hydrogen Energy. The two companies have since announced the potential development of a $1.5 billion coal-fired power plant incorporating CCS in Western Australia.

Partnerships can bring benefits to Anglo American

Partnerships offer a number of benefits to Anglo American. They allow the Group to focus on what it does well while creating the potential to expand into areas adjacent to its core business. Anglo

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**Figure 1**

Fungibility of fossil fuels

- **PRIMARY ENERGY**
  - Natural gas
  - Coal
  - Biomass
  - Extra heavy oil

- **CONVERSION TECHNOLOGY**
  - Reforming
  - Gasification
  - Syngas conversion
    - Fischer-Tropsch
    - Oxygenates
    - Chemicals
  - Power generation
  - Enzymatic/biological conversion
  - Refining processes
    - Coking
    - Hydro-treating
    - Novel thermal processes
  - CO₂ capture

- **PRODUCTS**
  - **FUELS**
  - **CHEMICALS**
  - **ELECTRICITY**
  - CO₂ for Enhanced oil recovery/storage

*Source: BP*
American has the opportunity to create value for its shareholders through accessing its partners’ complementary resources, including markets, technologies, capital and people. Importantly, as many of the growth opportunities are in the form of large-scale, multi-billion dollar industrial projects, partnerships also enable the Group to share costs and risks and grow more quickly and efficiently.

These principles have motivated the approach taken by Anglo American in the formation in 2006 of its Clean Coal Energy Alliance with Shell to develop Monash Energy in Australia and now the Xiwan project in China, the FutureGen Industrial Alliance in the US and Anglo Platinum's fuel-cell venture with Johnson Matthey.

Anglo American recognises that stakeholder engagement is also critical to ensuring the success of these projects and many of the issues faced are also common to the Group’s partners and peers. In collaboration with its partners and a number of its peers, Anglo American is also seeking to influence policy direction in a number of local bodies and at a global level. The Group has membership of a number of policy-influencing and stakeholder-engaging organisations, including the World Business Council on Sustainable Development, the World Coal Institute, the Coal Industry Advisory Board of the International Energy Agency (IEA), the IEA Clean Coal Centre, the Carbon Sequestration Leadership Forum, the International Emissions Trading Association and the Global Roundtable on Climate Change. Anglo American has also joined the Global Legislators’ Organisation for a Balanced Environment (GLOBE), which aims to build global political consensus around climate-change solutions.

**Monash Energy and the Clean Coal Energy Alliance**

The Group acquired control of Monash Energy Ltd (Monash Energy) in 2004. The key asset of the company was its exploration licence over a resource of over 13 billion tonnes (with more than 500 years’ life) of low-ash, low-cost brown coal, located in the Latrobe Valley in Victoria, Australia.

The Latrobe Valley is the centre of Victoria’s power-generation industry, with close proximity to infrastructure, ports, refineries, the city of Melbourne and a skilled workforce. It is also located within 200 kilometres of an equally vast geological reservoir beneath the Bass Strait, which is potentially suitable for large-scale storage of CO$_2$ (Fig. 2). The exploration licence had been granted by the Victorian Government on the basis of a proposal to establish Australia’s first commercial coal-gasification and GTL plant for the production of low-sulphur liquids (predominantly diesel) and the generation of power. The licence also set a limit on the emissions of CO$_2$, and so it was proposed that the gas produced would be placed back into the ground using CCS.

Anglo Coal continued to develop the project once full ownership of Monash Energy was acquired but, given the considerable technical challenges and scale of the project, being several billion dollars in size, it recognised that other partners and investors would be needed to add value and share risk. The universe of potential partners was first identified by determining the key project streams (such as mining, GTL and CCS) and ranking them according to their perceived level of risk in terms of the technical challenges involved and the range of possible solution providers. Then, in August 2005, a workshop was held to identify the preferred potential partners on the basis of their capabilities, both technical and operational.
particularly in the higher-risk project streams, and their alignment with Anglo Coal’s strategic objectives. Discussions then began with Shell. The Clean Coal Energy Alliance with Shell to further develop Monash Energy and other projects was subsequently announced in May 2006 and in the following September a Joint Development Agreement was signed to progress the project, on a 50:50 basis, from the concept to the pre-feasibility stage.

The key attraction of the alliance is that it provides an opportunity for Anglo American and Shell to share risk and create value through a combination of their skills, resources and capabilities, underpinned by shared corporate values and a common commitment to sustainable development. Anglo American’s competences in the coal value chain in accessing coal resources, mining and emerging skills in CCS are complemented by Shell’s proprietary technologies in gasification and GTL, as well as its CCS capabilities and product marketing. It was recognised early in the discussions with Shell that further exciting opportunities existed for the two companies and greater benefits would accrue if the partnership could be leveraged over further projects.
“Our partnerships with global leaders like Shell demonstrate our leadership and continuing commitment to clean-coal technology,” says Neil Dhar, Anglo Coal’s head of business development and one of the key people behind the Clean Coal Energy Alliance. “By sharing knowledge and know-how with our partners, we are able to maximise the speed with which we can transform clean-coal technology into a commercial reality, thereby helping ensure coal’s position in the future energy mix.” The two partners continued to hold discussions on other coal-related projects in Africa and Asia and in April 2007 it was agreed that a joint team from Anglo Coal and Shell would investigate the potential for developing a downstream coal project at Anglo Coal’s Xiwan reserve in China.

**The Xiwan Project**

Through its Xiwan project, the Group is looking to develop and beneficiate an open-cut coal resource of more than 600 million tonnes suitable for opencast mining, giving it a 50-year life, in Shaanxi province in eastern China.

The project effectively commenced in 2004 when Anglo Coal and the Shaanxi Coalfield Geological Bureau (SCGB) signed an agreement to jointly conduct exploration work on the resource. In addition, the Chinese authorities stated that approval to develop the resource would be conditional on the coal produced being converted in the same region into higher-value products. In parallel, Anglo Coal, in partnership with the Tianchen Chemical Institute, therefore started an analysis of the downstream options for the resource. Anglo Coal recognised that the potential scale and technical complexity of the project, along with the new markets to be accessed, were again likely to require the involvement of partners.

In August 2006, Anglo Coal and the SCGB formed a Co-operative Joint Venture to further develop the deposit. In addition, Shell and Anglo Coal have recently commenced a detailed study of the full range of commercial options for developing a potential $4 billion downstream project through gasification of the coal and subsequent conversion into gas, fuels or chemicals. Options for carbon management are also being reviewed.

**The FutureGen Industrial Alliance**

The FutureGen Industrial Alliance was established in 2005. Co-operating with the US Department of Energy (DoE) in a public-private partnership, its purpose is to design, construct and operate the world’s first commercial-scale, ‘near-zero-emission’ power generation plant that produces electricity and hydrogen fuel from coal while sequestering CO₂. The DoE will provide funding for 74% of the project cost, currently estimated to be around

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**Figure 3**

*FutureGen Industrial Alliance*

- Peabody
- CONSOL Energy
- American Electric Power
- China Huaneng Group
- Rio Tinto
- Anglo American
- Xstrata
- Foundation Coal
- BHP Billiton
- Southern Company
- Pennsylvania Power and Light
- E.ON
- US DoE

**Note:** All members have an equal interest

*Source: FutureGen*
Through the shareholding in and long-term research and development agreement with speciality chemical company, Johnson Matthey, Anglo Platinum is exposed to the commercialisation of fuel cells. These hold out the promise of being the major ‘next wave’ driver of platinum demand both in vehicles and stationary applications.

In February 2006, Anglo Coal, through Anglo American, joined the Alliance, becoming its ninth member. The Alliance has since gained a further three members and with coal-mining companies and power utilities from the US, Europe, China and Australia, it represents a truly international collaboration (Fig. 3). China, South Korea and India have joined the government side of the partnership, which is co-ordinated by the DoE.

Anglo American saw a number of attractions in joining the Alliance. First of all, it provides a low-cost and -risk approach to participate in the development of clean-coal technology. Although the individual technologies exist, they have not yet been integrated into a single, commercial-scale plant. The FutureGen project will both integrate the technologies and advance them in selected areas.

Although any intellectual property created by the Alliance will only be made available to its members on normal commercial terms, Anglo American sees value in being part of the journey as well as the destination. It provides an opportunity to network and learn from a geographically diverse set of Alliance members, all acting towards a common goal, and Anglo American potentially may apply these learnings to its other projects. As some of the members are power utilities, there is also the opportunity to work with coal consumers to lead them towards a sustainable solution to retain coal in the long term energy mix.

**Johnson Matthey Fuel Cells**

The majority of the output of Anglo Platinum, the world’s leading platinum producer, is currently supplied into the automotive-catalyst and jewellery markets. Recognising that, in the long term, demand for autocatalysts may be affected by the increased use of cleaner fuels or by other propulsion technologies, in 2002 Anglo Platinum acquired a 17.5% stake in Johnson Matthey Fuel Cells Limited, the fuel-cell components subsidiary of speciality chemicals company Johnson Matthey plc. Anglo Platinum contributed its share of the intellectual property rights, developed under an existing long-term research and development agreement with Johnson Matthey, and made an additional payment in return for the stake.

The acquisition has provided Anglo Platinum with exposure to the commercialisation of the jointly-developed fuel-cell technology. Barry Davison, then executive chairman of Anglo Platinum commented, “The development of fuel cells is a logical extension to our strategy of growing the market for platinum group metals. Fuel cells will drive the long-term demand for platinum and this strategic holding will provide commercial returns as well as stimulate demand.”

**Conclusion**

The supply of energy and its sustainable use has become one of the major geopolitical issues of the 21st century. Increasing demand for energy and the emergence of new technologies are providing emerging market opportunities for Anglo American. However, serving these new markets requires the Group to move outside of its traditional core business. Building on its core mining competencies, the company is therefore forming partnerships to monetise its mineral resources and serve these new markets in a sustainable manner.
### Monash Energy

**It’s a gas for King Coal**

The Monash Energy project envisages a phased approach to development of a coal-to-liquids (CTL) facility in Australia’s Latrobe Valley in the state of Victoria capable of converting 70,000-80,000 tonnes of brown coal or lignite into 60,000-70,000 barrels of transport fuels per day for at least the next 40 years. The fuel would make a significant contribution (8%-10% of the total) to the Australian transport-fuel market, reducing its import dependency.

The Latrobe Valley is Australia’s most concentrated producer of energy, with four major power stations drawing more than 60 million tonnes per annum of the region’s vast lignite resources.

The proposed Monash Energy facility would incorporate an on-site open-cut coal mine, coal-drying and gasification steps, and gas-to-liquids (GTL) conversion. In a very significant contribution to environmental protection, it would also have infrastructure for compression, transport and storage of excess carbon dioxide (CO$_2$).

The fuel produced by the project would be high-quality, virtually-zero-sulphur synthetic liquids, principally diesel. This ‘GTL fuel’, offers a range of environmental benefits compared with those derived from crude oil. As it is produced from a synthetic gas virtually free of contaminants, it is extremely clean and improves the efficiency and reduces the pollutant load whenever it is used in or blended into crude-derived fuels for diesel engines. Engines designed specifically for GTL fuels have the potential for even greater improvements in efficiency and reduction of pollutants (up to 85% reduction in carbon monoxide, for example).

A key step is the conversion of brown coal into a synthetic gas (‘syngas’), using Shell’s proprietary coal-gasification process. Since Victoria’s brown coal has a moisture content of slightly more than 60%, the Monash Energy Project will incorporate a preliminary drying stage to reduce this content to levels suitable for gasification.

To gain experience and data in this process, Monash Energy in 2005 extracted 1,500 tonnes of lignite from the district and transported it in sealed containers to a pilot steam fluidised-bed drying plant constructed by German energy giant, RWE, at Frechen in North Rhine-Westphalia. The coal was dried to a moisture content of approximately 12%, and then transported to a different site in Germany where it was gasified successfully.

Although the Monash Energy Project is focused on the production of synthetic transport fuels, the technologies it is demonstrating can equally be applied to the production of electricity, where the syngas is combusted. It is for this reason that nationally and internationally there is great interest in the potential of gasification and carbon capture and storage (CCS) to enable the emergence of a new generation of coal-fired power stations with dramatically reduced greenhouse gas profiles.

What the Latrobe Valley offers Monash Energy as a site for potentially the world’s first CTL plant to incorporate CCS, is its outstanding ‘source-sink’ match, with:

- a massive, low-cost, and largely consistent coal resource;
- an excellent site for geological storage of excess CO$_2$ which would otherwise make development of the project problematic on environmental grounds;
- close proximity between the two in order to minimise CO$_2$ transport costs.

Early studies into the potential of geological storage of CO$_2$ from the process have concentrated on the nearby offshore Gippsland Basin of the Bass Strait, with an estimated CO$_2$ storage potential of storage potential of up to 6 billion tonnes.

In the longer term, further applications of the clean-coal technologies established by Monash Energy could form the focal point for an industrial ‘hub’ providing the power, chemical and other industries in the Latrobe Valley with a sustainable future. This prospect is one of the many reasons why the project enjoys the strong support of the Victorian state government.

Anglo American and Shell are supplying key people to the project team, with Shell providing the engineering-design services for the concept phase. Monash Energy is a large-scale, long-term, capital-intensive project and the engineering-design work and commercial investigations are scheduled to continue over the next few years.

The project team has developed a sustainable development strategy for the project and is engaging with key stakeholders, including local communities and environmental NGOs. It has provided considerable input to the federal government over the development of legislation to provide a stable and workable regulatory framework for the safe and secure injection and storage of CO$_2$ in the deep sub-surface structures of Australia’s offshore waters.

The Monash Energy project is creating interest around the world as a CTL project, and also as a potential early adopter of CCS. As the project intends to combine the two, Anglo American is part of what could be a landmark first-of-a-kind project in moving the world towards a new energy future. ◆

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### The CTL process

- **Coal Mine**
- **Drying**
- **Gasification**
- **FT* Liquids**
- **Fuels**
- **CCS**

*Source: Monash Energy, CTL & GTL Conference, Brisbane 2007*
The road to lower emissions

BMW: Glimpsing a carbon-free motoring future

In late 2006, BMW launched the latest model in its 7-series, the Hydrogen 7, a car that is unique because its internal combustion engine is powered by hydrogen as well as petrol. Whereas other ‘hybrid’ cars being developed feed hydrogen into fuel cells to produce electricity, BMW’s model combusts liquid hydrogen, which is stored in a vacuum-sealed tank at –253°C.

The car has its practical drawbacks, but BMW believes it does much to establish the company as leading the field in green-technology development. The fact remains, though, that most electricity is generated from fossil fuels and until it can be produced on a huge scale from economically feasible and renewable resources, the production, storage and transportation of hydrogen on a commercial scale affect the climate no less than the refining of crude oil. A litre of hydrogen, too, is less than one-third as efficient as petrol in BMW’s vehicle: it consumes an average of 13.9 litres of petrol, but 50 litres of hydrogen, to cover 100 kilometres.

Moreover, with hydrogen’s use in vehicles being so new, there are as yet hardly any filling stations supplying it. The hydrogen capacity in BMW’s car takes it 200 kilometres. Its petrol tank provides a further 500 kilometres, but at an environmentally unacceptable rate of consumption by a 194 kW engine that is less efficient than one fuelled only by petrol. Until hydrogen refuelling stations are created in significant numbers, BMW will drive hydrogen bowsers to wherever motorists need topping up, which, critics point out, adds more environmental cost to using the vehicle.

All that said, however, BMW can justifiably claim to be a leader in moving the world’s automobile industry away from its century-long reliance on the internal-combustion engine towards one that will contribute near-zero noxious emissions, thus making for a more sustainable energy future.

Daimler-Benz: Cleaning the evil out of diesel

The use of petrol- and diesel-fuelled road vehicles continues to grow in the European Union (EU) countries at about the same rate as the region’s economic growth, polluting the air with carbon dioxide and other greenhouse gases, as well as with particulate matter (PM) visible as soot. All of which affects not only the climate but also people’s health, causing respiratory and cardiovascular disease.

In 1993 the first compulsory EU standards covering exhaust emissions of new road vehicles became effective. To meet those standards, which were different for the various categories of vehicles, manufacturers fitted catalyst filters and particulate traps to exhaust pipes.

Over the years, the standards became steadily more demanding. For example, in 1996 diesel vehicles were allowed to emit 80–100 milligrams of PM per kilometre driven. Those that come into effect in 2009 will allow only 5 milligrams. So, too, with oxides of nitrogen (NOx): diesel vehicles were allowed to emit 500 milligrams per kilometre in 2000. That figure was subsequently halved in 2005, and by 2009 will be further reduced to 180 milligrams.

Can future standards, which are expected to be further tightened in 2014, be met? The question is particularly pointed in the case of diesel-fuelled vehicles. Because they are more fuel-efficient than petrol-powered vehicles, they comprise about half of EU cars. But they also emit four or five times more PM and NOx.

Daimler-Benz’s answer to the question is a confident affirmative. Advances in exhaust-gas technology, involving not only an oxidising catalytic converter and diesel particulate filter but also innovative systems for reducing NOx emissions, now enable its diesel-powered vehicles, whether trucks or cars, to meet the 2014 emission standards. They are, claims Daimler-Benz, the cleanest diesel-powered vehicles in the world. ◆
GLOBAL ENERGY SECURITY –

FOSSIL FUELS

AT THE HEART OF A BURNING ISSUE

DANIEL LITVIN
Until recently, the issue of energy security was rarely debated with much excitement except perhaps in obscure governmental working groups or university seminars on 1970s geopolitics. Suddenly, however, it has become a hot topic again. Together with climate change, an issue these days increasingly mentioned in the same breath, energy security has become a major theme of political and media debate, particularly since the start of 2006.

In his State of the Union address in January 2006, for example, President George W Bush surprised the world (particularly given that he is a former oilman) by proclaiming that “America is addicted to oil” and setting out the “great goal” of significantly reducing America’s dependence on supplies from the Middle East. In January the same year, politicians across Europe began an intense debate about the risks of dependence on imported Russian gas, after Russia had temporarily halted gas supplies to the Ukraine. These sort of anxieties were heightened further later in the year by soaring oil and gas prices. Meanwhile, the debate about climate change was also becoming increasingly noisy in many countries. In Britain, for example, the publication in late 2006 of a government-commissioned economic study, The Economics of Climate Change: The Stern Review, which argued that the impacts of climate change could cost as much as 20% of global GDP, was described by Prime Minister Tony Blair as a “wake-up call to every country in the world”.

To top it all, in November 2006, the International Energy Agency (IEA) published its annual World Energy Outlook, a generally sober publication whose warnings this time of potential global energy crises made headline news in many regions. The IEA’s executive director warned of the potential for “skyrocketing prices or more frequent blackouts... more supply disruptions, more meteorological catastrophes – or all these at the same time.” Such worrying scenarios helped ensure energy security remained a significant theme of global political debate in early 2007 too, including most recently at the G8 summit in June.

What has driven energy security up the political agenda in this way? What are the prospects for averting the worst outcomes going forward? And what are the likely effects of increased insecurity on the world’s energy mix? The focus of this article is on energy security (and particularly of primary energy supplies). However, none of these questions – and certainly not the last – can be answered without factoring in concerns about climate change too.

There is also a common theme in the answers to all of the questions: the importance of collaborative and long-term solutions. One of the underlying causes of today’s energy-security problems, for example, is that both governments and companies in the past have often focused on securing short-term outcomes or adopted approaches which appeared sensible on an individual basis, but which perversely sowed the seeds for longer-term or collective challenges. In the same way, one of the key factors that will now determine whether current energy-security concerns (and indeed climate change) get worse or better is whether governments and companies now avoid repeating such short-term, and narrowly focused, patterns of behaviour.
To understand first of all the recent re-emergence of energy security as a high-profile political issue, it helps to start with economic and geological factors – albeit these provide only a partial explanation of the trend.

**Fuelling concerns**

Over the last year or so, concerns have grown about the potential for long-term mismatches in demand and supply for two of the most significant fuels in the world’s current energy mix: oil and gas. Whereas demand for both fuels is predicted to rise significantly in the next few decades, supplies are expected to be increasingly derived from a small group of countries which happen to be geologically blessed with large, and cheap-to-exploit, reserves. Growing realisation of this potential long-term trend partly underlay the spikes in prices in 2006, and the first half of 2007.

On the demand side, the world’s overall energy needs are expected to be around 50% higher in 2030 compared with today, according to IEA predictions, with the increase driven by both economic and population growth. For all the current attention focused on renewable energy, 80% of this increase is predicted to be met by fossil fuels – that is, oil, gas and coal. Industrialisation in Asia, and particularly in China, has recently driven energy demand faster than many analysts had anticipated. Between 2000 and 2004, for example, both GDP and oil demand in China grew by more than 8% annually. The process of industrialisation is often naturally energy-intensive. Also OECD countries have increasingly outsourced their heavy industry to Asia, adding to that region’s fast-growing appetite for energy, as Enno Harks’, an energy expert in the German government, pointed out in a recent article.

On the supply side, it has become increasingly apparent that efforts by OECD countries to find and produce oil from fields outside the Middle East are starting to bump up against some natural limits.
Certainly western nations had some initial successes in this respect in the decades following the oil shocks of the 1970s. However, many of the domestic oil and gas fields which were opened up in this period – for example in the North Sea and Alaska – are now approaching the end of their lives.

In this way, the imbalanced geological distribution of oil and gas reserves is now expected to re-assert itself over the next few decades. With the Middle East holding two-thirds of the world’s remaining oil reserves, for example, exports from the region are expected to be increasingly critical to meeting the expected increases in global oil demand (though boosting Middle East oil production sufficiently to meet these needs will require major increases in capital investment).

In terms of gas, meanwhile, three countries – Russia, Iran and Qatar – sit on 60% of the world’s reserves.

Correspondingly these countries are predicted to be increasingly important exporters of gas going forward – certainly if the expected growth in world demand is to be met. (Coal, the third major fossil fuel, by contrast, is distributed much more evenly across the globe, and also in larger quantities – a point which will be returned to at the end of the article.)

All of this might matter less, of course, if it were just market economics and geology dictating energy trends. Any excess of demand over supply for oil or gas would cause prices to rise, but this in turn would induce more supply and also curb countries’ appetite for energy. Actual disruptions
to energy supplies should be avoidable. Yet that ignores the array of political pressures and other real-world motivations and constraints faced by both exporters and importers of energy. It is these short-term dynamics which lie at the heart of the security concerns.

**Political sparks**

Focusing first on the exporters, many of the countries with the largest reserves suffer obvious political instability. Iran, Iraq, and Saudi Arabia, together sitting on a fifth of the world’s proven reserves, for example, are all run by governments facing significant internal threats or external pressures or both. Nigeria, another major exporter, struggles to control violence in its oil-producing region, the Niger Delta (its oil exports in 2006 were significantly reduced as a result).

Political pressures also help explain another common phenomenon in many non-OECD energy-rich states: a lack of investment in expanding production capacity. The state-owned firms which are in control of energy production in many such countries, for example, are often treated as cash cows by governments. The revenues they generate are frequently used to fund welfare or public programmes viewed as important by politicians or rulers, but this is sometimes at the expense of re-investment necessary to maintain or expand oil or gas output (and energy production is still often considered too ‘strategic’ a sector to allow in foreign investors, particularly in the Middle East). The IEA has highlighted the current relatively low rates of energy investment in both the Middle East and Russia as key factors which may prevent world production capacity responding to the expected growth in demand.

Then there are explicit attempts by governments to restrict energy supplies. Most famously, OPEC, the Middle East-dominated oil producers’ organisation, has long sought to limit oil supply so as to keep prices relatively high. A study for NATO also recently warned that disrupting energy supplies on a sufficient scale could significantly damage international energy markets, and thus present an attractive political weapon to rebels of different sorts.

Venezuela’s left-wing and anti-American president, Hugo Chávez, for example, at one point recently threatened to stop exporting his country’s oil to America, a country he views as imperialist. (Mr Chávez has also recently nationalised investments by foreign oil companies in Venezuela.)

In Russia, where anti-western sentiment is more moderate, the state has nonetheless also been exerting increasing control over the energy industry – for example, Gazprom, the state gas monopoly, has gained control over the giant Sakhalin project which was once majority owned by Shell, and similar moves now appear possible against a major BP investment. Meanwhile, Russia’s move to raise gas prices to Ukraine in early 2006 was seen by many – though this was denied by the government – as a way of exerting political influence over its smaller neighbour. Reported Russian plans to route or re-route export pipelines away from disfavoured neighbours have been interpreted in a similar light.

In Nigeria, meanwhile, the rebel groups in the Niger Delta have attacked local energy infrastructure partly to gain attention for their political cause: they argue that poverty-stricken local communities have received too few of the economic benefits from oil revenues. In Saudi Arabia, rebels of a different sort have been at work: in 2006, al-Qaeda tried to blow up a major oil facility in the desert kingdom. Though it failed this time, the terrorist network knows that disrupting energy supplies on a sufficient scale could significantly damage western economies. The IEA, meanwhile, recently warned that maritime export routes for Middle East oil are vulnerable to “piracy, terrorist attacks, or accidents”.

**Importing insecurity**

If short-term political dynamics and competition between different interests within the exporting countries are helping drive energy insecurity,
however, a broadly similar statement can be made about many importing countries too. In particular, many large energy importers, rather than collaborating to secure sufficient supplies of energy for long-term economic growth globally, appear to be engaging increasingly in head-to-head, and potentially damaging, competition in this area.

Admittedly, the importing countries are undertaking a variety of uncontroversial and sensible policies to reduce insecurity – for example, encouraging energy efficiency within their own economies, working through organisations such as the IEA, and promoting additional domestic energy production.

The potential for a future supply crunch, however, has meant that the major importers also now appear to be focusing hard on securing access to particular overseas oil and gas provinces so as to protect their immediate national interests. This approach may cause other countries to fear being excluded from deals and thereby raise the level of energy insecurity overall. The fact that many of the most abundant remaining oil and gas fields are in Middle East countries still opposed to significant foreign involvement has made this short-term competition all the more intense in other energy regions (such as Central Asia and the Caspian region, Russia, and West Africa).

In Africa, for example, Chinese, Indian, American and other western companies and governments have all been working hard to persuade energy-rich nations to grant them licences to develop oil and gas fields, often with increasing fervour (some analysts have compared this rush to the imperial powers’ ‘scramble for Africa’ in the 19th century). Certainly the growing desire to secure access to energy has meant broader concerns sometimes appear to have been pushed aside. Western activists have complained that China has turned a blind eye to local human-rights abuses in the Sudan, for example, where it now has substantial oil investments. The Chinese have denied these accusations. Western investors themselves, of course, have often preferred not to raise human rights and ethical concerns too directly in their dealings with non-democratic, but energy-rich, states such as Kazakhstan.

The route of export pipelines from the energy-rich Caspian, meanwhile, has been the subject of intense diplomatic competition over the last decade – with the US, for example, pushing for routes that avoid both Russia and Iran. Further east, China and Japan have been engaged in a diplomatic tussle of their own over export routes from Russia’s Siberian oil and gas fields, with each country, predictably, wanting the energy to flow its way.

As well as these external factors, various domestic issues in importing countries have added to energy-security concerns too. For example, in the same way that many exporting countries have been investing too little in their energy industries, so there has been a lack of investment in many importing countries’ ‘downstream’ energy-supply systems – such as in oil
refineries, or gas and electricity infrastructure. In many cases, such facilities need to be expanded or upgraded to ensure uninterrupted supplies to consumers. In many developing countries indeed, millions of people have no access to modern forms of energy, such as electricity, in the first place. Part of the problem in many wealthy countries, meanwhile, has been protests from local communities, or ‘nimby’ (‘not in my backyard’) opposition, over the construction of major new industrial installations.

A final addition to this mix of worries, of course, is climate change. Extreme weather events, such as storms and hurricanes, for example, can easily knock out major pieces of energy infrastructure. In 2005, for example, Hurricane Katrina (though not necessarily itself related to global warning) caused a shutdown of much of the US Gulf Coast’s production and refinery facilities. Such events clearly have the potential to impact both importing and exporting nations in the future.

**Breaking the pattern**

So what are the prospects for averting the worst outcomes from this overall state of heightened energy insecurity? And what is the likely effect on the overall mix of fuels used to generate the world’s energy? The
answer to the first question clearly hinges on the extent to which governments, companies and other actors are able to avoid the patterns of the past, and develop longer-term, more collaborative approaches.

A variety of unpredictable factors, it should be emphasised, may help defuse the situation in the meantime. A major economic slowdown in China, for example, would significantly dampen the growth of energy demand. On the supply side, potential output constraints could be lifted by, say, the discovery of major new oil and gas deposits in OECD regions, or even a decision by Middle East countries to welcome foreign firms and invest more in production capacity. None of these developments seems very likely for the time being, however.

The importance of breaking the patterns of the past can be seen in the fact that many of the current challenges over energy security have their roots or at least parallels in earlier approaches. Over the decades, as mentioned previously, a common pattern has been for governments and companies to seek to fix problems or achieve outcomes in the short term, but thereby sow the seeds for broader or longer-term difficulties.

Over the last 70 years or so, for example, the major western energy importers such as America and Britain sought to secure their energy supplies by supporting friendly, but undemocratic, regimes in energy-rich countries, and sometimes by interfering directly in these countries’ political systems so as to ensure the oil kept flowing. This helped perpetuate poor governance in many countries, as well as general resentment of foreign interference. In this way, it helps explain some of the current instability in Iran, Saudi Arabia, Iraq and other major exporters. It also helps explain why resource nationalism remains a significant
political theme in all energy-rich developing countries today.

From the perspective of the exporting countries, meanwhile, past attempts on their part to restrain energy supplies, while achieving political or economic outcomes in the short term, often damaged their interests in the long term. A good example of this is OPEC’s squeeze on supplies in the 1970s. This led to a huge increase in oil prices, and certainly raised the international political profile of the Middle East exporters. But it has also triggered an intensified search by western nations for energy reserves outside OPEC’s control, thereby weakening the cartel's share of the global oil market for several decades. Similarly today, energy exporters that threaten to withhold supplies of oil or gas may succeed in making a political point on the international stage – but they risk heightening energy insecurity among importing nations and thereby accelerating their search for alternative supplies and suppliers.

In this way, if all players today were focused on potential long-term, as well as short-term, outcomes, different approaches would likely be adopted. Importing nations might devote more attention to ensuring good governance, and
promoting local democracy and social stability in energy-rich countries and a little less attention to securing immediate exploration or export deals. Exporting countries would recognise their interest in investing in production capacity and boosting output so as to keep customers tied to them for the long term. All this would require greater collaboration (for example, between the importers, who would need to agree not to compete on the basis simply of short-term favours offered to exporters) and also more far-sighted leadership (for example, on the part of energy exporters who might need to divert money from popular social projects to long-term re-investment in energy).

For this reason, it may not be wise to bet on such an outcome. True, there are some promising signs: for example, the Extractive Industries Transparency Initiative, a collaborative project aimed at improving governance through the transparent reporting of revenues from energy and mineral production, has gained the support of a number of importers and exporters. Even so, political reality and old habits are likely to die hard.

**Want more gas? Look northward, angel**

*Thomas Wolfe: Look Homeward, Angel*

Natural gas offtake is growing steadily. Current US consumption is forecast to rise from 65 to 85 billion cubic feet per day (bcfd) a decade hence, with the amount having to be imported rising from 10 to 25 bcfd. Similar import forecasts have been made for other developed economies owning natural-gas reserves.

Those imports will come from the Middle and Far East and Africa, together accounting for about half of known reserves, or from Russia and Central and South America, containing most of the remaining reserves. But while natural gas can be transported thousands of kilometres across land by pipeline, it is not feasible to do so by submarine pipelines. The gas must be liquefied by lowering its temperature to –163°C, thereby enormously reducing its volume for marine and road transportation. Despite the high cost of doing that, liquefied natural gas (LNG) consumption is forecast to treble over the first 20 years of this century.

That still, however, leaves LNG importers dependent on countries or regions not famous for their political stability. Hence the welcome from Western Europe and the US to the Norwegian project to harvest gas from beneath the Barents Sea, then liquefy and export it. The Norwegian krone 58 billion (approx. $10 billion) project, known as Snohvit (Snow White) because it lies deep inside the Arctic Circle, comes on stream this year and is expected to earn more than three times its investment by 2030.

There are many remarkable aspects to the project. It is the first time Barents gas resources are being exploited. The platforms for doing so do not float on the sea’s surface but lie on its bed, feeding gas through a 160-kilometre pipeline to an on-shore liquefying plant. Gas extraction and pipeline transportation are remotely controlled by operators located 140 kilometres away in Melkøya.

Importantly, carbon capture and storage (CCS) technology will also be tested as part of this project.
In fact, if the potential mismatch between global energy demand and supply materialises as predicted over the next few decades, it may be that all the political dynamics underlying the current levels of insecurity only become worse. Higher oil and gas prices will make it easier and more tempting for exporters, or rebel groups within them, to use energy as a political weapon. Similarly, the scramble by importers to secure remaining reserves may intensify, with the potential even for violent conflict for control over energy-rich regions if any of the major importers feels excluded or economically endangered by lack of supplies.

All mixed up

Finally, examining the potential impact of such insecurity and other factors on the world’s energy mix, and particularly on coal, provides another example of the importance of collaboration. An obvious potential implication of growing insecurity is to tilt the balance in favour of fuels less vulnerable to disruption. True, production of all major existing fuels, including oil, gas and coal, will likely need to rise significantly over the next few decades if the expected growth in global energy demand is to be met. However, the effect of energy insecurity – at least isolated from other factors – should be to support the fastest growth of energy sources considered relatively secure. This would include renewable energies, such as solar and wind power, nuclear power (assuming, that is, current public opposition to this technology in many countries can be overcome) – and also coal.

Coal deposits, as mentioned previously, are not only reassuringly widely distributed across the globe (for example, America, Australia, China and India all have major domestic reserves), they are also further from exhaustion than the other fossil fuels. At current rates of production, proven global coal reserves will last for over 150 years, compared with around 40 years for oil and 64 years for gas. All this, together with the favourable economics of coal as a fuel for electricity generation, help explain the fast growth in global coal consumption currently. China and India are driving much of this increase. China, for example, is reported to be opening a new power station fired by coal every few days.

If climate-change concerns are fed into the equation, however, the world’s long-term energy mix becomes more difficult to predict. As noted earlier, debates about energy security and climate change are becoming increasingly intertwined, with concerns about security making it politically easier for governments to start to push ahead with reforms to tackle climate change, and vice versa. Yet unlike nuclear and renewable energy, which score well on both security and climate concerns (and also unlike gas which is relatively environmentally friendly), coal is currently seen to be a big part of the problem in terms of climate change.

Coal, as it is now used, accounts for some 38% of the world’s carbon dioxide (CO₂) emissions from fossil fuels, thus making it currently a controversial choice for nations seeking energy sustainability as well as security. Importantly, however, various collaborative projects between major companies and governments are now under way to develop ‘clean coal’ technology (one possibility, for example, is to capture and store underground the CO₂ from coal-fired power stations, potentially making coal as benign in this respect as renewables). The trouble is that, for the time being, such technologies are often uneconomic, and remain at the research stage. Almost all coal is still currently burned in a climate-unfriendly way.

Assuming governments begin sooner or later to act on their stated desire to make deeps cuts in global carbon emissions, the success or otherwise of such ‘clean coal’ technology collaborations could therefore become critically important for the coal industry. If such collaborations make only incremental progress in the future, then the current rise in coal demand – whatever its security benefits – could tail off and go into reverse over the long term. If, on the other hand, energy companies and governments devote greater efforts to working together in this area, and thereby succeed in proving the effectiveness and economics of clean coal, then the sector could guarantee its growth for the very long term. As with energy security itself, the extent of collaboration and far-sighted leadership among key actors holds the key to creating positive outcomes from a potential crisis.

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THE AUTHOR

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ILLUSTRATION

Hein Botha
Towards a more sustainable future
An NGO perspective
Tony Juniper
The release of billions of tonnes of carbon dioxide (CO$_2$) into the atmosphere each year is now known to be changing the Earth’s climate. The 2007 Fourth Assessment Report from the Intergovernmental Panel on Climate Change (IPCC) sets out in a worst-case scenario the alarming prospect of potential average global temperature increases of more than 6°C by 2100. Such a rapid dramatic change in environmental conditions would lead to devastating impacts on the environment, entail trillions of dollars’ worth of economic damage and cause humanitarian impacts on a scale never before experienced. Worse still, it will be the poorest people who will suffer first and worst as a result of rapid climate change, for example because of impacts on food production and because of the spread of disease facilitated by warmer temperatures. Even warming of 3°C (a quite likely prospect if we do not take immediate action) would lead to extremely serious impacts.

Although about a fifth of annual CO$_2$ emissions is being contributed by deforestation, atmospheric change is being mainly driven by the combustion of fossil fuels. As the world’s use of coal, oil and gas increases year on year, so the problem becomes more urgent. Rapid industrialisation in developing countries such as China and India, the spread of western-style high-consuming lifestyles across the world, coupled with sustained increases in energy demand in most developed countries, means that annual emissions are steadily increasing.

While energy use goes up, the latest climate science warns that we must urgently reduce emissions. Concentrations of CO$_2$ have already rocketed up from about 280 parts per million (ppm) in the pre-industrial atmosphere to over 380 ppm now. When the warming effect of other climate-changing gases (such as methane and nitrous oxide) is included, then there is already an equivalent of about 430 ppm CO$_2$ in the atmosphere. Recent modelling suggests that to stand a reasonable chance of avoiding a 2°C global average temperature increase (widely seen as a danger threshold of warming that must be avoided) CO$_2$ equivalent (CO$_2$e) concentrations must not exceed 450 ppm.

With annual increases of about 2 ppm, this gives about a decade for a peak and rapid decline in emissions to occur.

**Threats to energy supply**

At the same time that countries are confronted with this challenge, many are also increasingly aware of looming threats to energy supply. In the West the principal concern in this respect is mainly in relation to securing long-term access to oil and gas. As global oil consumption in particular increases, so concerns that demand might soon outstrip supply become more acute. Major new oil finds have been few and far between in recent decades, while some experts have expressed real doubts about the reliability of some claims made by oil producers as to the actual volume of known reserves. Alongside matters of security and conflict this situation has undoubtedly spurred some countries to look at alternative fuels. The recent announcement by President George W Bush of American intentions to increase dramatically the use of plant-derived alternatives to oil (so-called...
"Concentrations of carbon dioxide (CO$_2$) have already rocketed up from about 280 parts per million (ppm) in the pre-industrial atmosphere to over 380 ppm now. When the warming effect of other climate-changing gases (such as methane and nitrous oxide) is included, then there is already an equivalent of about 430 ppm CO$_2$ in the atmosphere."

Gallo/Getty
biofuels) underlines the seismic shifts in policy that are now taking place.

Climate change and energy security are real, big and urgent issues that need to be addressed now. Action is needed to tackle these challenges for reasons of economic stability, to protect human welfare and to maintain the functioning of the planet’s life-support systems, ranging from coral reefs to tropical rainforests. It is not now a matter of if we are going to act, it is a question of how.

The penny appears to finally have dropped, at least in some countries. In the UK early 2007 saw the publication of draft laws on climate change with proposals to set in place legally binding targets to reduce emissions substantially in the coming decades – for example to achieve a 60% reduction in CO₂ emissions by 2050, with interim targets met through the allocation of rolling carbon budgets. This is a very positive step, for which the British government is rightly being credited with an international leadership role. The real test, however, will be in the policies and measures that are put in place to actually deliver CO₂ emissions reductions while at the same time improving energy security – and doing that in a way that doesn’t worsen other environmental challenges. It’s a tall order, but we have no choice but to rise to it.

First step: reducing energy wastage

Fortunately, there are a range of easy wins that we can get under our belt quickly. The most immediate step is to reduce energy wastage. Public-information campaigns can do this quickly, as was found during the 1970s following oil price shocks that led some governments to conduct high-profile campaigns to save energy. Certainly, culture change is needed but that could be done quite fast, if the political will is there to do it. With the lights still left on all night in government buildings, there is clearly still some way to go in making that change more visible and credible.

The positive impacts of behaviour change can also be bolstered with measures to ensure that the energy we do use gives maximum benefit. A range of energy-efficient technologies are now available that can dramatically decrease the power needed to run homes, offices and factories. From energy-efficient light bulbs to new technologies that...
dramatically reduce the power wastage from appliances left on stand-by, to super-efficient combined heat and power systems, a lot of what we need is already available, but not being sufficiently widely used. Some products (such as inefficient incandescent light bulbs) should be removed immediately from sale.

More efficient vehicles could make a huge contribution, too. Research conducted for the British government estimates that a 60% cut in CO₂ emissions from the surface-transport sector could be achieved by 2030 – for example, through investment in alternatives to car use, including safer cycling routes, as well as new laws that would require manufacturers to meet higher fuel-efficiency standards. More local production would also help to reduce emissions from the transport sector – for instance, in reducing mileage that is clocked up by food.

The aviation sector will need to play a role as well. Rapid growth in the number of flights is leading to increased emissions of CO₂, which at high altitude has a particularly serious impact, causing more than twice as much warming as equivalent pollution released at ground level. Technology can play a small role, but until there is a major breakthrough that delivers a step-change in aircraft design there is inevitably a need to curtail growth through demand-management measures, such as fuel duties (from which the sector is presently exempt).

What about renewables?

Renewable energy technologies are also a vital part of the mix of solutions. Wind, wave, tidal and solar technologies already work and are being used, but need to be scaled up dramatically if climate-change and energy-security goals are to be met. Emerging technologies that have huge potential need to be deployed on a large scale, such as concentrating solar power (CSP), which uses mirrors to concentrate the heat of the sun to boil water, and thus drive steam turbines. One estimate for the potential of this energy source suggests that from just 1% of the world’s hot deserts it would be possible to generate the equivalent of present world electricity demand. CSP could also provide a pollution-free source of hydrogen for use in fuel cells.
Making buildings not only more efficient but also equipped with the latest micro-generation technologies, from solar hot-water systems to small-scale wind turbines (where they work, which is not everywhere), and from ground-source heat pumps to small-scale biomass combined heat and power systems, could make a huge impact on emissions. New enterprise and jobs could be created too, if policy-makers create new markets; for example, through new, more sustainable, buildings standards.

There are also technologies that would render some continued use of fossil power considerably less damaging. By capturing carbon and injecting it into geological deposits, including former gas and oil fields, emissions can be slashed. A report from the IPCC sets out the huge potential for this technology. Carbon capture and storage (CCS) technologies thus should at least be used as an interim measure to reduce emissions while the transition to a truly sustainable energy economy takes place.

A report prepared by the Tyndall Centre for Climate Change Research for Friends of the Earth showed how action can be taken to use all of the above approaches to cut back UK emissions by 90% by 2050.

... and nuclear power?

Some experts argue that we urgently need to build a new generation of nuclear power stations. Nuclear power is a relatively low-carbon electricity-generating technology, but it is not cheap. One US study found that a dollar invested in energy efficiency can get seven times more carbon reduction than a dollar spent on nuclear. In taking action to reduce the risks of catastrophic climate change it will be important to get the biggest benefit from the resources available. History has shown how nuclear is not likely to be a strong contender in this respect.

Aside from cost, there are increasingly pressing matters linked to global nuclear proliferation. Undoubtedly there will need to be far stronger international agreements if there is to be any serious chance of avoiding the worst impacts of global warming. This in turn will require countries to agree about which technologies will be used in carbon-reduction strategies. If western countries use nuclear as an explicit climate response, and then tell others that they cannot do the same, the chances for a durable global accord on climate change will be considerably diminished. This is why the diplomatic stand-offs with North Korea and Iran over fears about nuclear weapons proliferation should be taken very seriously in how we judge the future usefulness of this technology.

Getting renewables going alongside more efficient energy use, making cars cleaner and getting traffic levels down, installing micro-power systems in buildings and making fossil generation cleaner and more efficient is a better package. All this has a vital added benefit: we can start now. New nuclear power would not come on stream for at least 15 years.

... and biofuels?

Another approach that has been strongly advocated in order to both bring down overall emissions and to secure energy supplies is the expanded use of biofuel. Plant-based alternatives to diesel and petrol can help to diminish the climate impact of transport fuels because when plants grow they take CO₂ from the air. But burning fuel from the plants in engines is only a temporary contribution – that is, for as long as new crops are planted to take the same amount of CO₂ out of the air again. Biofuel can also decrease reliance on imported oil.

There are serious downsides, however.

Biofuel cultivation needs land: lots of it. In Brazil there is large-scale use of sugar-derived bio-ethanol (a petrol alternative). This has certainly meant less reliance on oil and oil imports, but has serious environmental downsides in the loss of forests to make way for huge sugar cane cultivation. Biofuel production can thus place pressure on land that is important for conserving ecosystems.

In Brazil the rapid expansion of soya production for food is already causing high levels of rainforest loss. If soya is additionally grown to make biofuel, then the devastating land-use changes that have taken place in recent years could actually accelerate. Similarly in Indonesia and Malaysia, where the huge recent expansions of palm oil plantations providing a source of cheap fat for the food industry are also increasingly seen as a source of fuel for vehicles and power stations. Palm oil plantations today are not
only associated with massive environmental destruction but also serious social impacts and human rights abuses.

Then there are questions linked to the energy used in the cultivation, processing and distribution of biofuels. Fossil energy is used in agricultural machinery and in converting crops into petrol and diesel alternatives. There is also a major fossil energy input into the production of fertilisers and pesticides. All this of course leads to CO₂ emissions. So does transporting biofuel to market. If biofuels are being transported around the world, and manufactured with large-scale fossil-energy input, then their overall environmental benefit will be considerably reduced. If they are also cultivated at the expense of rainforests, then the climate-change impact might be actually worse than using petrol.

In a world with a rapidly growing human population, it is also essential that our energy choices anticipate future pressure on land arising from increased demand for food. In this respect it is instructive to note that the land needed to fill the tank of a Range Rover just once with biofuel is equivalent to that needed to feed one person for a whole year. Demand for agricultural crops, such as maize, to produce fuel will also impact on commodity prices. This has already happened, with Mexican grain prices increasing in response to US maize demand to manufacture ethanol.

If we are to reap benefits from biofuels, then they need to be produced with a series of environmental safeguards put in place. These must relate to the protection of important ecosystems such as rainforests, the type of land being cultivated, the production methods employed, the energy used in manufacture and the distribution to market. It will also be necessary for policy-makers to keep close watch on how expanding biofuel use impacts on food security.

Even if it is possible to effectively certify the environmental credentials of biofuels, the emphasis must remain firmly on greener motoring based on efficiency first, and on alternative fuels second. Filling a gas-guzzler with biofuel can hardly be regarded as a sound environmental choice when there are cars that are more than twice as efficient. Governments must not only, therefore, ensure that an effective biofuel-certification scheme is in place; they need to ensure that more efficient vehicles are sold as a matter of legal requirement.

Emissions trading
Alongside specific measures targeted at particular sectors or technologies, governments must help accelerate the transition to a low-carbon economy through economy-wide policy frameworks that encourage more sustainable energy choices. One powerful means to do this is via emissions trading. The European Union already has a trading scheme in place, although many say that at present it is too weak and delivering insufficient financial incentives to firms to reduce emissions.

For emissions trading to work, not to mention delivering stronger energy-efficiency standards and dramatic growth in renewable power supply, the active collaboration of the private sector will be necessary. This, in turn, must entail not only technological innovation but also the more active involvement of business leaders in negotiating how the transition to a low-carbon and more secure energy future can be achieved. There is every reason to be optimistic that this can happen, but more leadership is needed in this respect.

The challenge of climate change and energy security
To date, the response of many companies to the climate-change and energy-security challenge has been either to protect particular industrial interests or to argue that markets rather than regulation are the correct way to proceed. Certainly, markets have a role to play, but CO₂ cuts of 80% or more by 2050 will not be delivered solely through the operation of markets. Laws and policies are needed as well.

Measures to address the challenge of climate change and energy security are often portrayed as negative and posing a threat to growth and personal freedom. Reality could be somewhat different, however. New technologies that generate jobs and new business opportunities, as well as clean power, offer huge opportunities for development as well as the environment. Embracing a vision for a cleaner, more sustainable and secure future is not only necessary, but also desirable.◆

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OPTIMA SEPTEMBER 2007 41
Biofuels

“Proceed with caution”

JOHN COLLINGS

Biofuels have been around for many decades, but in only a small way until recently. What has made them a hot topic in the past year or two has been rising concern over oil – its steadily rising price, shrinking reserves, and ownership used as a political weapon – and global warming. Some maintain biofuels could significantly help to address both those concerns. An International Energy Agency (IEA) report published earlier this year said biofuels’ contribution to meeting transport-energy needs could rise from the present 1% to 7% by 2030.

Politicians have not been slow in promoting biofuels. US President George W Bush has proposed that 35 billion gallons of them be produced annually in the US by 2017. That would amount to 15% of US liquid-fuels use projected for that year. The European Union (EU) has similar ambitions for biofuels: 5.75% of liquid fuels consumed by its 27 member nations by 2010 and 20% by 2020.

Such targets trouble environmentalists and others. Earlier this year a lengthy United Nations document was published, Sustainable Bioenergy: a framework for decision makers, which spelt out the opportunities and possible negative effects of a major increase in global biofuels production. While it declared that “sweeping generalisations about the efficacy of particular approaches are rarely valid,” its implicit message was clear: proceed with caution.

Environmentalists protest that biofuels match people against cars and other vehicles because they consume mostly the same crops. Bioethanol is produced from starch or sugar found in corn, wheat, sugar cane and rice. Biodiesel is derived from sunflower, soybean, peanut or palm oil, as well as from animal fat.

Loek Boonkamp, of the Organisation for Economic Co-operation and Development, has calculated that replacing a mere 10% of the world’s current petroleum use with biofuels would consume 30% of all grain, oilseed and sugar presently being produced in North America, the EU and Brazil. So far, biofuels production accounts for only 1% of global fuel production and, according to the IEA, crops grown for it take up just 1% of the world’s currently available arable land.

Nevertheless, with rapidly rising volumes in recent years, it has been a significant contributor, along with ever more expensive crude oil, to soaring corn, wheat and sugar prices. The corn price led in turn to higher meat, milk and egg prices.

It could get rapidly worse for the world’s poor, whether in developed or developing economies. The US provides over 70% of world corn exports, but in some of its leading corn-growing states biofuels already take more than half of the grain harvest. Similar levels of crop diversion from food to biofuels might happen in the developing world. In May this year the US Department of Energy’s statistical and analytical agency released its International Energy Outlook 2007, which forecasts energy developments over the period 2004-2030. Against a global average annual increase in demand for transportation energy of 1.7%, China’s annual rate will be 4.9% and India’s 3.3%. China and India are already building ethanol plants using rice and grain. Thailand plans to begin producing ethanol from cassava, while Malaysia and Indonesia continue investing heavily in biodiesel plants, using palm oil as the feedstock.

In South America, Brazil, which already meets 44% of its total energy needs from renewable sources, mostly by producing ethanol from sugar cane, has announced plans to expand into biodiesel production, using soybeans, castorbeans and palm oil. Argentina, a proven low-cost producer of biodiesel and keen to win lucrative export markets, announced 13 biodiesel projects last year, and a further six so far this year. Total investment in Argentinian biofuels is forecast to reach $1 billion by the end of this decade.

Nor has Africa hung back from the challenge. In 2006, 13 countries formed the Pan-African Non-Petroleum Producers Association, and South Africa was one of four African countries to formally adopt pro-biofuels policies to guide its participation in the industry.

Over the next 15-20 years a quarter of the world’s energy needs could be met by biofuels, observes a senior executive in the United Nations’ Food and Agriculture Organization. What would be the effect of planting crops for that purpose on such a massive scale? Would the poor, urban and rural, benefit? And what would be the local and global environmental effect?

Sustainable Bioenergy says that answers to those questions have to consider local climatic, agronomic, economic and social circumstances. In principle, though, the rural poor could benefit by finding additional markets for agricultural output, by gaining new employment opportunities, by being able to replace unhealthy sources of heat (wood and cow dung) for cooking with biofuels, and by having access to electricity and all its associated benefits.
On the other hand, they would lose the use of land on which they presently subsist, but do not own, if it were taken over by large, vertically integrated biofuel companies. That land, which presently perhaps has considerable biodiversity and is therefore able to accommodate a range of crops, might be given over to monoculture. That, as Australian experience of rapidly expanded sugar cane production in New South Wales has shown, can be disastrous for water resources, especially for wetlands which play an essential role in water-catchment areas, in the maintenance of water quality, and the preservation of fish and bird habitats. Forests, too, could be cleared on a massive scale to make way for biofuel crops.

Meanwhile, the urban poor could suffer from rising food prices if the most agriculturally productive land were given over to biofuels crops. And that change in land usage would happen when a continuing oil-price rise, or cost reductions in the growing of crops and biofuel production, made biofuels price-competitive with fossil fuels even without government tax and other concessions.

Proponents of biofuels argue that they are less environmentally harmful than fossil fuels when it comes to greenhouse emissions. Not necessarily so, says Sustainable Bioenergy: the level of carbon emissions varies considerably between different types of plant and, it adds, forest clearing conducted to make way for biofuel crops could produce higher levels of carbon emission than the use of fossil fuels.

Forests are also far more effective than crops at absorbing carbon from the air, say environmentalists. They also point to the herbicides, pesticides and fertilizers used for crop growing. All of them are produced using electricity, which is also used in fuel-producing plants – and electricity is produced by burning fossil fuel, which is also the source of the petrol or diesel that powers tractors and harvest-transporting trucks. Some maintain that almost as much energy from non-renewable sources is consumed to produce biofuels as the latter yield, a point that is supported by Sustainable Bioenergy, which maintains biofuels currently need tax breaks to be commercially viable.

Which is not to say that things couldn’t get a lot more promising for biofuels given major technological breakthroughs. This year’s US federal budget proposes to increase funding (by an unstated amount) for bioethanol and biodiesel, specifically to support construction of an industrial-scale ‘biorefinery’ that the government hopes will demonstrate the attractions of these fuels to large investors and consumers.

Bioethanol and biodiesel are, however, usually described as being mere first-generation biofuels. The future is widely thought to lie in the development of biofuels made from inedible plant material: ethanol made from the cellulose in wood rather than from sugar or starch, and synthetic diesel made from the processing of woody biomass. Progress already achieved in lignocellulosics, as the technology is known, indicates a far greater efficiency in converting the energy of these materials into biofuels than has been achieved in producing first-generation biofuels.

Some scientists believe second-generation biofuels could become competitive with fossil fuels within the next 10-15 years, and also contribute to carbon dioxide abatement. Sustainable Bioenergy points out, however, that wood used for lignocellulosic biofuels production will be the residue of forestry and agricultural activities, which should be left where it lies since it replenishes the soil and protects it from rain, sun and wind, and lowers the risk of erosion.

Environmental commentators are more demanding. What is needed, they say, is not new fuels to reduce demand for fossil fuels in privately-owned vehicles, but either a reduction in the use of such vehicles – accomplished by providing better public-transport systems and other measures – or their use of ‘clean’ electricity through fuel cells and batteries.

The last word on biofuels, at least for the moment, has perhaps been provided by International Energy Outlook 2007. It forecasts that by 2030 they will account for less than 2% of the world’s total liquid-fuels production.

The Author

After reading history at Oxford University, Johannesburg-based John Collings spent some years in broadcasting in England, Zambia and South Africa before becoming a wide-ranging journalist and author. His most recent book, Mind Over Matter, explains for the layman how Sasol, South Africa’s synthetic-fuels pioneer, developed its technology over the first half-century of its existence.
Brown-coal- or lignite-fired unit of the 3,900 megawatt Niederaussem electricity-generating plant of German public utility RWE. The unit incorporates optimised plant engineering and has achieved an efficiency level of 43.2%, an all-time high for power generation from lignite.
In the 21st century, the world faces twin energy-related threats: that of not having adequate and secure supplies of energy at affordable prices and that of environmental harm caused by consuming too much energy in inappropriate ways.

A solution to either of these threats is relatively straightforward; however, a solution to both simultaneously is one of the great challenges facing the world in the 21st century. With global energy demand expected to rise by 53% over the next 30 years, and fossil fuels accounting for 83% of the overall increase, simply calling for a cut in consumption is not a sufficient solution to the challenges we face. Moreover fossil fuels – and coal in particular – have an important role to play in enhancing energy security and fuelling both economic growth and poverty alleviation globally. Finally, technological innovations and continuing security concerns about oil and supplies are driving developments.

The industry’s response to these challenges will dictate whether our descendants simply view coal as a strangely primitive fuel, or whether they will see it as a strategic resource that was able to fuel and safeguard their future and was supplied by an industry focused on technological innovation and responsible product stewardship.

**Coal's significant growth and the role of China**

Coal is now the world’s fastest-growing fuel. It was the fastest-growing fuel in 2006; for the period 2000-2006; and for the decade from 1995 to 2006.

Over 70% of this increase is coming from developing countries and most of that comes from China (and to a lesser extent India).

In 2006, global coal consumption grew in all regions, except North America and the Middle East. As well as China, growth was particularly strong in India, Indonesia and the UK (see graphs opposite).

China alone represented 72% of the growth in world coal consumption in 2006 and almost 52% of the growth in total world energy consumption.¹

Today, China is both the world's largest producer of coal and the world's largest consumer – accounting for just under 40% in each case. Over the next five years it will build a new coal-fired power station every few days to support growth in its economy of about 10% per annum.

China's reliance on coal, and its pre-eminent position as a producer and consumer, means that it will need increasingly to engage with the concerns of its neighbours in the Asia-Pacific region, with the global community and with the political and commercial environment confronting the coal industry globally.

**Shifting policy environment**

The critics of coal have long attacked it, with little regard to the benefits that it has brought as an affordable and widely available fuel. To its critics, “Coal is a commodity utterly lacking in glamour. It is dirty, old-fashioned, domestic, and cheap...children may have heard the warning that if they are bad, they will find nothing but a lump of coal in their Christmas stockings.”²
In fact, coal has a strong record of positive contribution to the world. Coal provides 28% of all primary energy and 40% of the world’s electricity. It is also a direct input into 66% of global steel production. As an affordable and accessible fuel, it would be hard to overstate the importance of coal to raising many developing countries out of poverty. Today, 1.6 billion people in the world have no access to electricity and that number will still be about 1.4 billion by 2030. However, coal has driven poverty eradication and successfully attacked electricity deprivation in many areas of the world.

- In China, 700 million people over the past 20 years have been provided with access to electricity. Today, the country enjoys an electrification rate of about 99% from a generation industry 77% fuelled by coal.
- In India, since Independence in 1947, electricity generation has risen from 4 billion to 400 billion kilowatt-hours (KWh); from 30,000 kilometres of transmission lines to 4 million kilometres; and 85% of villages have been connected to the grid by a power industry 68% fuelled by coal.

**Location of the world’s main fossil-fuel reserves**
Gigatonnes of coal equivalent

![Map of Global Fossil Fuels](image-url)

Source: BP and WEC
In South Africa, the electrification rate has doubled in a decade from 35% to 66%, served by a power-generation industry 90% fuelled by coal, and both the motor-vehicle fleet and aircraft are supported by coal as a liquid fuel.

To get some idea of the effects of energy poverty you need only contrast South Africa with its neighbours in Sub-Saharan Africa, which lumbers under an electrification rate of only 10% and where 575 million people are dependent on primitive, labour-intensive and erratic sources such as biomass for their energy.

The good news is that the past two years have seen a re-assessment of the role of coal by the major economies and their governments, and the possible beginning of a shift in sentiment towards coal, coincident with rising concerns about energy security and climate change and other major issues.

Energy security

Recently we have seen oil prices exceeding $75/barrel and pledges by OPEC to defend a long-term price floor of $60/barrel; the disruption of gas supplies from Russia to Europe through the Ukraine (January 2006), gas through Georgia (December 2006), and oil through Belarus (January 2007); and the dramatic impact on oil supplies to the US arising from damage to oil infrastructure in the Gulf of Mexico from Hurricane Katrina.

This reminds us that both oil and gas are heavily concentrated in Russia and the Middle East; and that half of this century’s gas is located in just two countries – Russia and Iran.

The potential of coal to underpin enhanced global energy security is obvious:

- It is abundant and mined in more than 50 countries around the globe.
- It is found in both developed and developing countries.
- It is affordable in comparison to its energy competitors.
- It is safe and reliable. BP itself calculates global reserves of oil to last 41 years, gas 63 years and coal 147 years at current consumption rates.

Of course, changing economics will enable commercialisation of some reserves and there may...
always be new discoveries. For example, in January 2006, Brazil’s state-owned oil company, Petrobras, announced it had discovered what it called a huge new offshore oil field off its coastline. Petrobras estimated it contains at least 700 million barrels of crude. However, the unfortunate reality is that the world is using about 84 million barrels of oil each day. In other words, what Petrobras refers to as a ‘huge’ new field will only supply the world for 8.3 days. To meet the energy demand challenge of this century with oil we would need a string of similar ‘huge’ discoveries – in fact, one every week.

No wonder then that companies like Centrica – the UK’s largest gas supplier – in addition to buying electricity from the coal-fired Drax power station, is investing in the development of a new coal-fired power plant at Teesside. Even the gas giant Centrica needs to reduce its exposure to high gas prices and the inherent insecurity associated with gas supplies.

Against this background, the world will need a greater contribution from renewable energy and it may even need more nuclear energy. But there are natural and human limits on the extent to which energy demand can be met by nuclear and renewables.

Nuclear is limited both by its economics and by serious concerns about the treatment of nuclear waste and the proliferation of nuclear weaponry. Hydro is a significant player globally, but the world appears to have reached or be reaching an upper limit on opportunities for large-scale hydro projects. Similar to Centrica investing in coal, even the operators of the Three Gorges Dam in China bought five coal mines in 2006 to lessen what they themselves called ‘hydro risk’.

Without hydro, other renewables barely register. China announced in November 2006 that it intends to build the world’s largest solar power plant – supplying 100 megawatts (MW) of electricity and costing $770 million to build. It is 10 times larger than the current largest (in Germany), but 100 MW hardly compares with Drax in the UK, for example, which supplies 4,000 MW of power! And, of course, renewables are hostage to shifts in weather.

The basic fact is that a global electricity market that is today supported 80% by fossil fuels and 1%
by solar and wind power, is not going to turn its back on coal in the near future. As the executive director of the International Energy Agency (IEA) put it in 2006, “Fossil fuels still supply most of the world’s energy in 2050 and the demand for oil, natural gas and – in almost all scenarios – coal, are all greater in 2050 than they are today. The investment in these conventional energy resources remains essential. But we can use them in much cleaner and more efficient ways.”

For these reasons, governments are looking more closely at the vital role of fossil fuels and coal within their economies.

**Climate change**

It is the environmental challenge that the coal industry recognises it needs to confront to ensure its ability to contribute further to economic growth, poverty alleviation and energy security.

Coal has demonstrated a capacity in the past to rise to environmental challenges and overcome them and the industry is not shying away from its challenges now. It has responded to concerns about nitrous oxide (N₂O) and sulphur dioxide (SO₂) emissions, and about particulate matter; the great challenge now, of course, is carbon dioxide (CO₂) emissions.

Confronting climate change will require greater effort from the industry and greater collaboration between governments, the coal producers and coal users – particularly the power-generation sector. It would be misleading to understate the enormity of this challenge. However, a technological pathway is open to near-zero carbon emissions from coal use – through carbon capture and storage (CCS). In this regard, the UN Intergovernmental Panel on Climate Change found that:

- Costs of stabilising CO₂ emissions can be reduced by 30% or more by including CCS in mitigation portfolios.
- Power plants with CCS could emit 80%-90% less CO₂ net.
- The majority of CCS technologies are either economically feasible under specific conditions or part of a mature market now.
- Potential leakage from appropriately managed storage sites is very likely less than 1% over 100 years and likely less than 1% over 1,000 years.

Construction work on the Three Gorges Dam at Yichang on the Yangtze in China. Even the operators of the dam have bought five coal mines to lessen what they themselves term ‘hydro risk’.

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**Unconventional petroleum liquids capital-cost investment**

(Work per daily barrel of capacity*)

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**Estimated CO₂ storage capacity and annual emissions**

Gigatonnes of CO₂

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**Emissions reductions from synthetic fuels – Europe**

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**Source:** Alliance for Synthetic Fuels in Europe, 2006

**Source:** Energy Information Administration

**Source:** World Watch Magazine, January-February 2006. Published by the World Watch Institute. Oil: A Bumpy Road Ahead, Kjell Aleklett
There is potential for 2,000 gigatonnes (Gt) CO₂ geological storage worldwide (see accompanying graph).\(^4\)

**Coal as a cleaner fuel**

Just as there is a technological pathway for the use of coal in power generation, there is also an opportunity for the greater uptake of coal via coal-to-liquids (CTL) in transport. And because it has environmental advantages over refinery diesel, CTL will be particularly relevant to cities like Beijing and Delhi that suffer from acid rain and smog due to transport emissions.

A study\(^5\) last year by a consortium of DaimlerChrysler, Renault, Volkswagen, Shell, Sasol (South Africa’s synthetic-fuels producer) and Chevron illustrated that there are significant pollution reductions in moving from normal crude-oil-based fuels to liquid-transport fuel derived from coal.

The study illustrates environmental benefits in shifting from oil to coal. To begin with, the refinery process removes SO₂, so motor-vehicle SO₂ emissions are reduced 100%. The study then found that CTL reduces N₂O emissions by 5% in existing engines and 45% in optimised engines; particulate matter by 25%-40%; hydrocarbon emissions by 45%-60%; and carbon monoxide by 40%-85% (see graph opposite). Some of these are greenhouse gases, some are the main constituents of smog and acid rain – all directly impact on the environment and human health.
The environmental benefits of gasifying rather than burning coal to generate electricity have scientists forecasting it will be at the core of clean-coal technology for many years. Because it uses coal’s energy to drive gas as well as steam turbines, less coal is consumed, so less carbon dioxide is produced. The latter can be produced in a concentrated stream that is relatively easily captured for sequestering. Other gas constituents – hydrogen, ammonia and sulphur – are also captured, using well-established techniques, and sold.

The latest coal-gasifying power stations, such as that owned by the Dutch utility Nuon, gasify plant-derived biomass as well as coal. Some use natural gas as a third fuel. ◆

Above: An artist’s impression of the Nuon multi-fuel plant at Eemshaven in the north of the Netherlands

Courtesy of Nuon, Netherlands
With regard to CO₂, CTL diesel is 30% more efficient than normal crude-oil fuels, which means cars use less fuel for the same journey and so can emit less CO₂. Finally, the CTL refinery process is ideally suited to the capture of process CO₂ for storage underground.

In terms of pricing, we already know that coal itself has consistently maintained prices well below oil and gas and was never subject to the price volatility that plagues those fuels. Princeton University has most recently estimated that CTL can be commercial at oil prices of between $27 and $45 per barrel. This is well below current prices and is at or below the US Energy Information Administration’s lowest price forecast for world oil prices for the next quarter-century.

So CTL – a technology that has been around for about 100 years and has been used on a commercial scale in South Africa since the 1950s – offers an opportunity for coal in a world concerned with rising oil and gas prices, energy security and even environmental protection – provided it can be used in conjunction with CCS.

Until this decade, and the recent rises in oil and gas prices, it has been economics rather than technology that has held back the wider commercialisation of CTL. Undeniably the capital costs in building a CTL plant are currently higher than a conventional oil refinery, and may require some form of government support, but they are lower than other alternatives, including biomass to oil, oil sands, and shale oil.

At the end of the day, one suspects that the American and Chinese economies, sitting atop hundreds of years of coal reserves, and facing both huge annual oil-import bills and supply-insecurity and -instability challenges, will drive the rapid exploitation of CTL and drive down those prices, not just in motor vehicles but in all forms of transport.

The same economies could well be at the forefront of the cleaner-coal revolution that needs to focus on solving our twin energy-related threats: that of not having adequate and secure supplies of energy at affordable prices and that of environmental harm caused by consuming too much energy in inappropriate ways.

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**Coal: an essential part of the energy mix for the future**

The world is confronted by enormous challenges with regard to poverty alleviation, energy security, and climate change. The view from the World Coal Institute is that far from being a fuel of the past, coal will prove increasingly indispensable to meeting those challenges.

There is much talk in western capitals of the need to transfer capital and the requisite technologies and expertise to the developing economies and China in particular. Not for the first time, China may well surprise us all.

At the end of 2006, China overtook Japan and became the world’s No. 2 research and development (R&D) investor after the US. Since 1995, China has not only more than doubled its R&D spending, from 0.6% to 1.3% of GDP, but has increased its number of researchers by more than 77%. Although its economy is growing at some 10% per annum, its R&D intensity is increasing even faster. According to Vice Science and Technology Minister Wu Zhongze, the Chinese National Medium- and Long-Term Science and Technology Development Plan (2006-2020) will “prioritise technological developments of energy, water, resources and environment protection, and is determined to solve major bottlenecks in China’s socio-economic development.”

The coincidence of those global challenges and a growing awareness of technologies that can support a more efficient and environmentally responsible use of coal reserves in power generation and as a transport fuel indicate that coal will be with us for quite a while yet.

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1 BP Statistical Review of World Energy 2006
3 Claude Mondil, Bridging the Energy Gap, Address to the Dialogue Meeting on Climate Change, Clean Energy and Sustainable Development, Monterrey, Mexico, 3 October 2006
4 Intergovernmental Panel on Climate Change, Special Report on Carbon Capture and Storage, 2005
5 Source: Alliance for Synthetic Fuels in Europe, 2006
Oil’s steadily rising price in recent years, together with concern about its future availability from some major producing countries, has greatly increased western investors’ interest in Canada’s oil sands. Formed about 50 million years ago, and located mostly in the province of Alberta, the sands contain bitumen, a tar-like oil from which fuels and other products can be made.

Covering an area of about 140,000 square kilometres, the sands are estimated to contain more than 1.7 trillion barrels of bitumen, of which about 315 billion barrels might be recoverable if improved extraction technologies were developed. With about 174 billion barrels of bitumen thought to be recoverable using current methods, the known reserves are exceeded only by Saudi Arabia. This is enough, according to the Canadian Energy Research Institute, to meet Canada’s oil needs for the next 250 years, though the US is seen as the major market for the sands’ product.

The bitumen in the sands is not a new discovery: fur trappers and explorers reported seeing it more than two centuries ago, and the sands were scientifically surveyed in 1875. Strip mining of the sands and bitumen recovery began in a small way in the 1920s, but those who later began doing it on a commercial scale were generally thought to be taking a wild gamble. By the late 1970s there were still only two oil-sands projects of significant size.

As recently as the mid-1990s the official forecast was that production of bitumen from the sands would reach 1 million barrels a day in 2020. Subsequent oil-price rises saw a surge in mining of the sands, and that forecast was achieved by 2004. The current forecast by the Canadian Association of Petroleum Producers is that bitumen production could reach 3.5 million barrels a day by 2015, making Canada the world’s third or fourth largest oil producer (it is currently the seventh).

The proviso attached to that forecast is that all 40 major bitumen-recovery projects so far announced for the period 2006-2015, involving an annual average capital investment over that period of US$10 billion, are completed by the latter date. There are major challenges or uncertainties that could cause investors to rein in their enthusiasm for further exploitation of the oil sands. They were spelled out in a recently published report by the Canadian House of Commons Standing Committee on Natural Resources, which investigated the sustainable development of the oil sands.

Those challenges and uncertainties cover the future price of natural gas, the price difference between light and heavy oils, management and government monitoring of air emissions and water usage, the availability of sufficient skilled labour, the provision of infrastructure and services in a rapidly developing region, and protection of the natural environment on which many aboriginal Canadians depend. The report’s conclusion is that government, both federal and provincial, as well as private-sector organisations will have to collaborate more closely in developing the oil sands to avoid errors that could prove disastrous.

A brief description of how mining the oil sands and extracting bitumen is conducted will help explain the sustainable development challenges.

It begins with exposing the orebody. This involves removing trees, then draining, removing and storing the top layer of earth. Evidence offered to the standing committee by a major oil-sands mining company was that it could take up 10 years to restore an area to the condition it was in before clearing of it began. Others, however, are sceptical that complete restoration of mined areas to long-term ecological viability can be achieved, mainly because there is as yet, they say, no proof of it.

Meanwhile, an official estimate is that 42,000 hectares of land have so far been altered by oil-sands mining. The sand – actually a mixture of sand, clay, water and bitumen – is then scooped up into huge trucks and transported in ‘hydrotransport’ pipelines from the mine to the extraction plant. There the various components are separated from each other and the bitumen undergoes further cleaning and processing into synthetic crude oil. The energy used to achieve all this comes from electricity or natural gas.

Some 80% of Alberta’s bitumen lies at depths too great for strip mining to be practicable. Methods have therefore been devised to obtain it in situ – that is, by digging wells into which it will flow of its own accord, and from which it can be pumped to the surface. Where the bitumen’s viscosity is too great to allow it to flow naturally, steam is injected into the sand to heat the bitumen and thereby reduce its viscosity.

Energy for producing the steam comes from natural gas, a resource that was once abundant in the region. The report, however, records industry concerns about
the rising price of natural gas – a significant cost factor in extracting bitumen in situ and upgrading it – and whether there will be enough natural gas to cope with the 2015 production forecast, which could require some 2 billion cubic feet of natural gas against the 0.7 billion cubic feet used in 2005. Burning natural gas also produces carbon dioxide, the most commonly cited greenhouse gas. The report states that greenhouse gas emission per barrel of oil-sands bitumen is three times as great as that emitted in the production of conventional oil. All of which explains why the industry is seeking alternative energy sources to natural gas.

Future water availability and quality are another concern described in the report. It comes about because oil-sands exploitation is occurring upstream of the Athabasca River. Little of the water taken from the river is returned to it, creating concern that rapidly expanding production might leave insufficient flow in the river to keep its downstream aquatic ecosystem healthy, especially given the river’s very low flow rate in winter. That, in turn, would affect not only waterfowl, which enjoy one of the largest nesting and rest areas in North America, but also those aboriginal inhabitants of the region who fish the Athabasca.

There are, too, concerns about waste water in tailings ponds contaminating soil and groundwater with its salinity and acidity. Methods will have to be further improved and more widely employed, the report says, to reduce the amount of water used in bitumen extraction and to treat tailings so as to reduce the amount of water left in them. The challenge is not merely to reclaim land sufficiently that some plants can grow in it, but to restore forest and natural peat bogs. No reclamation method currently employed or suggested guarantees that.

The governmental organisation Natural Resources Canada believes that by 2030 as many as 5 million barrels a day of bitumen could be extracted from Canada’s oil sands. The standing committee’s report makes clear, however, that achieving even the 2015 forecast of 3 million barrels is not something that can be taken for granted.
The nature of appropriate precautionary action is, however, the subject of great debate in policy-making circles. Broadly speaking, there have been two camps in the industrialised countries. Those calling for immediate action advocate a range of measures to reduce current emissions. As regards business emissions, they want to see restrictions placed on the emissions of existing industrial plant as well as strong incentives to lower the carbon footprints of future plant. The European Union’s emissions trading scheme is perhaps the clearest, certainly the most important, example of implementation of this policy approach.

On the other side of the debate are those who say that the priority should be the development of new low-emissions technologies, and that the imposition of emission restrictions on existing sources will be unduly economically damaging in current circumstances. In their view, investment in research and development (R&D) (primarily by government) is needed first in order that low-emissions abatement technologies can become available at reasonable cost, so that they are viable for deployment in developing countries as well as the wealthier developed countries. The Asia-Pacific Partnership on Clean Development and Climate, comprising the US, Australia, Japan, China, India and South Korea, is an example of implementation of the low-emissions technology-policy approach.

The two policy approaches are not mutually exclusive and recent years have seen the emergence of policies seeking a balanced approach combining near-term emissions reductions in using existing technologies with the development of much-lower-emissions technologies for future deployment. Europe has begun to place more emphasis on low-emissions technology development than it has in the past, while support for the adoption of near-term constraints on emissions has been growing in the US.

In the developing world, policy-makers look to the developed world to provide both near-term mitigation of emissions, and new low-emissions technologies for longer-term deployment. Politicians here are certainly aware of climate change as an issue for their countries (tropical countries are expected to be negatively affected by climate change to a far greater extent) – but see the problem as having been caused by the industrialised nations and one that should in the first instance be addressed by those countries. This view is reinforced by the fact that the developed countries have greater available resources and do not face so many other pressing claims on those resources (such as those arising from food security, poverty, unemployment, disease, etc.).

At the global level this policy logjam is unlikely to be released soon and the Kyoto Protocol will be the main form that global carbon constraints take until its expiry in 2012. Yet future carbon constraints will be of critical importance for energy markets. Thus, a vital question for policy-makers and for businesses considering long-term energy investments is ‘What will follow Kyoto?’.
ENERGY SUPPLY
IN A CARBON-CONSTRAINED WORLD
IAN EMSLEY
Post-2012 Climate Change Policy Scenarios

In June 2006 a group of climate-change policy analysts* assembled at Anglo American in order to discuss the outlook for global climate-change policy post-2012. The exercise outlined post-2012 scenarios to illustrate the different outcomes that are possible within the agreed ‘Rules of the game’ governing scenario construction.

Rules of the game

Rule 1
Fossil fuels will remain the dominant source of energy in any conceivable scenario up to 2030 and in all probability beyond. Moreover, although coal might lose market share, it will still experience market growth in all scenarios. An important consequence of this fact is that unless there is an abatement solution that can be implemented for fossil-fuel emissions, and in particular for coal, there will be no climate-change policy that will limit carbon dioxide (CO₂) concentrations in the atmosphere to less than 550 parts per million (ppm), the level at which dangerous climate change is deemed likely to occur.

Rule 2
The Kyoto Protocol requirements represent only the start of the action required to limit CO₂ atmospheric concentrations to below 550 ppm. More action will be needed and this action will not be cost-free; in other words, there is no plausible scenario where emissions will be limited purely through business-as-usual decisions.

Rule 3
Public perceptions need to change. Currently an insufficient proportion of the public in the industrialised countries either believes that climate change is happening or that, if it is happening, it is of sufficient importance to require policy responses that incur any economic ‘pain’. The position of the US is critical to achieving any global post-Kyoto settlement and, accordingly, it is in the US that perceptions most need to change if a global settlement is to be reached. Unless they do, and thereby make more effective (and painful) policy action possible, there is not likely to be the required globally co-operative solution.

Rule 4
A truly global solution needs greater inclusiveness than the Kyoto Protocol has been able to provide. There has to be some degree of action by all significant emitting countries, but the highest per capita emitting countries need to make the greatest effort.

Rule 5
For developing countries to share any of the burden resulting from significant action to reduce emissions, there will need to be perceived co-benefits from such co-operation. Such co-benefits could include co-operation on energy security, trade, aid, defence, investment, etc.

Rule 6
Even in the most co-operative outcome, action will only be incremental. Radical action will only follow a possibly extended period of trust-building between countries. The process of arriving at an effective global climate-change policy can be seen as a ‘game’ whereby the best (co-operative) outcome is essentially unstable and can only be maintained by trust. Individual countries are unlikely to incur significant economic pain unless they are confident that other ‘game players’ will do likewise. This impediment to a co-operative solution is greatly reinforced by the long-term nature of abatement strategies. Individual countries are unlikely to invest in costly and long-lived abatement plans unless they are confident that their principal competitor nations will be making similar investments. The potential for an individual country to renege on the agreement and revert to unabated fossil-fuel use presents a threat that can only be allayed through the gradual building of mutual trust.

Key uncertainties

Taken collectively, these Rules of the game indicate a world in which progress towards a climate-change solution, at best, will be staged. The alternative, however, might be a world in which no action at all is forthcoming. There are a number of uncertainties, the outcome of which will be important in determining which of these two policy outcomes results.

*Anglo American post-2012 climate change-scenarios workshop – participation list.

External
Elliot Diringer, Director International Strategies, Pew Center on Global Climate Change; Paola Subacchi, Head, International Economics Programme, Chatham House; John Drexhage, Director, International Institute for Sustainable Development; Scott Foster, Managing Director of Global Gas & Power, Global Insight; David Keith, Professor of Economics, University of Calgary; Gideon Hoffman, Senior Policy Advisor; Stern Review Team; Harry Audus, General Manager, IEA Greenhouse Gas R&D Programme; Justin Mundy, Director, Climate Change Capital & Senior Policy Advisor to UK Government; David Hone, Group Climate Change Advisor; Shell; Simon Dent, Head of European Power & Gas trading, Paribas.

Internal
Clem Sunter, Scenario-planning Facilitator; Edward Bickham, Executive Vice President, External Affairs; Dorian Emmett, Head of Sustainable Development; Ian Emsley, Advisor: Carbon Management and Sustainable Development; Gareth Griffths, Managing Director, Anglo Coal Marketing Ltd; Karin Ireton, Head of Sustainable Development: Economics and Markets; Simon Thompson, then Chairman, Anglo Base Metals and Anglo Industrial Minerals; John Wallington, Chief Executive, Anglo Coal; Roger Wicks, Head of Energy: Anglo American.

In Brazil there is a sure understanding that the country is already part of a global community, and as such, it should participate in reducing emissions. In May 2008, for example, Brazil announced that it plans to reduce its national emissions by 36% by 2020. This commitment is consistent with the country’s vision of open markets, and its belief that the transition to a low-carbon economy is inevitable. In fact, Brazil is already making significant progress in this direction. The government has implemented a series of policies aimed at reducing emissions and promoting renewable energy, including a national climate change strategy, a national action plan, and a law that provides a framework for the implementation of climate change policies. These policies are being implemented in collaboration with the private sector, which has shown a growing interest in the low-carbon economy. In addition, Brazil is a key player in international climate negotiations, and is working with other countries to develop a global solution to climate change. Overall, Brazil is showing leadership in the fight against climate change, and is making significant progress in reducing emissions and promoting a low-carbon economy.
Energy prices
High energy prices resulting from scarcity or energy-security concerns arising from undue dependence on oil and natural gas will clearly increase the attractiveness of higher-cost renewable and low-carbon energy sources. However, coal prices are unlikely to rise greatly for any sustained period owing to the abundance and widespread distribution of low-cost reserves.

Political will
As noted previously, public perceptions, particularly in the US, need to change and be mobilised if politicians are to be mandated to take tough action. Greater agreement between scientists on the reality and impact of climate change would help bring about such a shift, but it is possible that only extreme climate events that threaten the perceived well-being of significant parts of the population will have sufficient power to achieve this result.

Mitigation and adaptation costs
It is rational for politicians to take action to reduce emissions only if the costs of such action (mitigation) are lower than the costs of adapting to climate change. Extreme weather events are likely to increase the costs of adaptation, or at least to bring these costs forward. Technological breakthroughs could reduce the costs of mitigation and thereby make it more acceptable. As the UK-government-sponsored The Economics of Climate Change: The Stern Review, published in October 2006, has emphasised, delay will increase the aggregate costs of mitigation by forcing a more rapid adjustment to any given emissions target.

Geopolitics
The Rules of the game state that climate-change-policy co-operation will develop only gradually. Trust-building in climate-change negotiation will be greatly facilitated by co-operative international relations in other areas of interest. A key question is whether the world will be inclined to greater co-operation in general or whether it will be divided by policy disputes in areas such as defence, energy, security, water, trade and investment. Global environment agreements will be particularly hard to sustain in a divided world. The failure of the Doha trade liberalisation round; the risk of

Melting ice has led to a shrinking habitat for the polar bear. “The scientific evidence that climate change is a serious and urgent issue is now compelling. It warrants strong action to reduce greenhouse gas emissions around the world to reduce the risk of very damaging and potentially irreversible impacts on ecosystems, societies and economies... Reversing the trend to higher global temperatures requires an urgent, worldwide shift towards a low-carbon economy. Delay makes the problem much more difficult and action to deal with it much more costly.”

The Economics of Climate Change: The Stern Review
economic nationalism and energy insecurity; and the ongoing conflict between liberal democracy and religious fundamentalism, all will make negotiations more challenging. Alternatively, a globalising world enjoying rapid and rapidly spreading economic growth is more likely to be well disposed to co-operate on climate change.

Continued warming and extreme weather events

Eleven of the hottest years on record globally have occurred in the last 12 years; such statistics represent one of the few tangible realities of climate change and are, therefore, politically important. However, it is possible that the world could enter a

Climate Change Policy Scenarios

The Climate Change Policy Scenarios developed by our workshop at Anglo American focused on two pivotal uncertainties: first, the degree of political will to implement economically painful policy measures and, second, the degree to which international relations will be harmonious or fragmented. Four possible worlds result from the combination of these uncertainties, humorously named after styles of dancing.

Strictly Ballroom

In this Scenario, the post-Bush US presidency signals a new readiness to negotiate a serious post-2012 policy regime and introduces relatively tough domestic measures (a federal ‘cap and trade’ scheme) which build on pre-existing state-level initiatives. Renewed political will in Canada, Japan and Australia is generated as a result of meaningful US participation. In a world of rapid economic development, more resources will be available to develop and deploy abatement technologies. Global investment agreements, in particular those addressing the protection of intellectual property rights, will facilitate higher cross-border investment flows and thereby the rapid uptake of state-of-the-art technology. Such developments will encourage significant developing-country emitters, such as China and India, to adopt loose reduction measures such as generous intensity-based targets. As a result, a global carbon market develops rapidly and the cost of mitigation falls owing to learning and scale economies, thereby encouraging yet more radical action.

Different Dances

Different Dances is a world where disputes between countries and regions are common. Nevertheless, the will to find solutions to the climate-change problem remains strong. Efforts will be varied and conducted on parallel, bilateral and unilateral lines. Given the threats to economic competitiveness that such disparate efforts will pose, there will be continuing policy-regime instability. Measures are likely to focus on technologies offering co-benefits, such as energy efficiency and energy security. Some states will attempt to achieve demanding targets in order to show leadership and within these jurisdictions carbon prices (implicit as well as explicit) could be quite high; however, the fragmentation of the global carbon market will result in higher costs for any given level of global abatement. The prevalence of international disputes in this world would limit the level of overseas investment and thereby limit technology transfer. This scenario is less stable than the others and would tend to resolve to one of the other scenarios over time.
cooling period, given that short-term climate fluctuations are typically large in relation to the warming trend. Such a cooling could result in a policy hiatus. Alternatively, an acceleration of warming could result in greater action.

Extreme weather events will probably be of greater significance in swaying public opinion than a gentle warming trend. Although climate science indicates little relationship between global warming and the frequency of hurricanes, there is support for the belief that warming will lead to hurricane intensification. More hurricanes of the sort experienced by the US in 2005 could provide support for a ‘tipping point’ in US public opinion.

Dirty Dancing

In this scenario there is little or no agreement, especially in the US, that climate change is a priority. As a result, other countries are not prepared to take serious action to reduce emissions, especially where competitiveness might be affected. Uncertainty is likely to be greater in the scientific community given the lower political will to fund research and, as a result, there might be a tendency to wait for the actuality of climate change to confirm the modelling forecasts. In a world characterised by economic nationalism and protectionist tendencies, economic growth and co-operation will be lower. As a result, emissions would also be rising less quickly, thereby temporarily allaying the concerns of some. Any co-operative measures that do take place would be likely to focus on adaptation rather than mitigation.

Dances with Wolves

In a world of harmonious relations but little concern for climate change, co-operation is likely to focus on form rather than substance. Agreement on a framework to succeed Kyoto could be reached but the commitments entailed in the agreement would be weak. Indeed, countries, while paying lip service to the agreement, might undermine it cynically in ways that maximise perceived national interest.
Elements of both the *Different Dances* and the *Dances with Wolves* Scenarios characterise the current global carbon-policy scene. The question is which scenario represents the most likely policy evolution in the decade following Kyoto. On the one hand, the current conjunction does not look particularly favourable to international harmonisation. On the other, at least at the level of rhetoric, there appears to be increasing political will in a number of countries to implement serious measures. Most importantly, the success of the Democratic Party in the mid-term elections has greatly increased the likelihood of meaningful action in the US. A case can be made for regarding the probabilities of the four Scenarios as quite evenly balanced.

**Abatement technology development in the different Scenarios**

All serious contributors to the debate on climate-change policy acknowledge the important role that technology development will play in securing climate stabilisation. The different policies adopted in each of the Climate Change Policy Scenarios would have very different impacts on the development of abatement technologies. The sorts of abatement technologies that might be implemented would, in turn, have very different impacts on the energy-supply industry. This section focuses on the abatement technologies that are likely to be adopted in the *Strictly Ballroom* Scenario and briefly points to the consequences of these choices for the energy-supply industry.

The following views are closely based on the work of the International Energy Agency (IEA) published late last year in its *Energy Technology Perspectives 2006*. This work examines the scope for technology-based solutions to greenhouse gas (GHG) emissions in the period to 2050, given the assumption of a range of abatement incentives. The IEA’s Accelerated Technology (ACT) Scenarios describe a possible low-carbon future based on technologies that are already largely currently available on a commercial or near-commercial basis. However, the full utilisation of these technologies will require the
presence of certain incentives, including support for R&D; demonstration and deployment support for technologies not yet commercial but with prospects for cost-competitiveness; instruments to overcome some of the non-economic barriers to technology uptake (such as required standards and better information provision); and, most importantly, a cost of carbon that rises to $25/tonne from 2030 in all countries.

The level of cost implied in the ACT Scenario is modest in the sense that it would be quite compatible with good economic growth, particularly if the revenues that accrued to government from imposing such a cost were used to reduce taxes. The scale of the additional required investment in the power sector is given as $3.4 trillion over the period 2003-2050, equivalent to 0.1% of global GDP in 2003. The incremental energy cost impact of costing emissions at $25/tonne CO\(_2\), is equivalent to 2 USc/KWh (kilowatt/hour) from coal-fired power stations (which equates to an approximately 50% uplift in current coal-fired generating costs – though with significantly lower percentage price increases for retail customers) or 28 USc/gallon on petrol costs.

The IEA’s ACT Scenario assumes a robust rate of world economic growth of 2.9%/year between 2003 and 2050. It also assumes that the demand for energy services remains the same as in the ‘business as usual’ IEA Baseline Scenario (i.e., all energy-emission changes are due to supply-side changes and demand-side efficiency changes). This is a very important assumption since it suggests that there would be little reduction in energy-based living standards relative to the Baseline Scenario. In effect, life as we have come to understand it in the OECD countries and to which people in the rest of the world mostly aspire would not be greatly changed by the envisaged policy changes.

In the ACT Scenario total global CO\(_2\) emissions in 2050 rise by 6% above 2003 levels. This level of emissions would not be compatible in itself with a stabilised climate, for which global emission reductions will need to be in the order of 60%. The ACT Scenario, however, does describe a credible pathway towards an eventual stabilisation of GHG atmospheric concentrations. Further steep emission reductions would be required in the second half of the century.

At the end of 2006, worldwide installed capacity of wind-powered generators was almost 75,000 megawatts. Although wind power currently produces less than 1% of world electricity use, it accounts for about 20% in a country like Denmark. Globally, wind power generation quadrupled between 2000 and 2006.
Principal technologies used in the ACT Scenario

End-use efficiency

Nearly half the required ACT Scenario emission reductions of 32 Gt (gigatonnes) CO\(_2\) relative to the Baseline Scenario result from end-use energy efficiency improvements. The efficiency gains are projected at 2%/year, as compared with 1.6%/year between 1973 and 2003 and 1.4%/year in the Baseline Scenario. Altogether, the efficiency gains deliver nearly a 15 Gt CO\(_2\) saving by 2050. These efficiency savings are assumed to result not from energy-price increases\(^5\) but from a wide range of non-price policy measures. There is a varied potential for efficiency gains but some of the larger opportunities arise in the transport and buildings sectors.

The transport sector is estimated to offer half the potential end-user efficiency gains and these arise principally from continuing incremental improvements in vehicle drive trains and in auxiliary systems such as air conditioners as well as reductions in weight and rolling/air resistance. Many of these gains are already borderline commercially viable and collectively would deliver about 4 Gt CO\(_2\) by 2050. The other form of transport-efficiency gain would result from the accelerated uptake of hybrid vehicles, which might deliver a 1.4 Gt CO\(_2\) saving by 2050. The IEA estimates that together these technology developments could deliver a 40% average fuel-economy improvement by 2050, which would limit the growth in fuel consumption by light-duty vehicles to 50% despite a 149% rise in vehicle kilometres over the period.

The buildings sector could also contribute greatly to increased end-user efficiency. Altogether, more energy-efficient buildings could deliver savings of more than 6 Gt CO\(_2\) by 2050. The principal measures that would contribute to this outcome include better insulation standards and more efficient heating, cooling, lighting systems and electrical appliances. In the industrial sector, the major potential lies in more efficient motor systems. These systems account for half of industrial power use and it is estimated that 1.5 Gt CO\(_2\) could be saved by 2050 through the realisation of this potential.\(^6\)

To realise these changes will require many detailed policy measures, especially in the setting of required efficiency standards for appliances and buildings. Implementation would have to overcome many barriers that currently limit the adoption of commercially viable efficiency standards, such as conservatism in technology choice, long product-replacement cycles and the different incentives facing equipment-purchasers and equipment-users.

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### Reduction in CO\(_2\) emissions in the IEA ACT Scenario by technology area

**Share of reduction below Baseline Scenario in 2050**

- **End-use efficiency:** 45%
- **Power generation:** 34%
- **Biofuels in transport:** 6%
- **Coal to gas:** 5%
- **Nuclear:** 6%
- **Fossil-fuel generation efficiency:** 1%
- **CCS:** 12%
- **Hydropower:** 2%
- **Biomass:** 2%
- **Other renewables:** 6%
- **CCS in fuel transformation:** 3%
- **CCS in industry:** 5%
- **Fuel mix in buildings and industry:** 7%

**Source:** IEA

### IEA energy supply Scenario projections

**Million tonnes oil equivalent**

- **2003 Actual**
- **2050 Baseline Scenario**
- **2050 ACT Scenario**

**Source:** IEA
Carbon capture and storage (CCS)
The second greatest contributor (at about 6.5 Gt CO₂) to abatement in the ACT Scenario is carbon capture and storage (CCS). By 2050 it is assumed that more than half of all coal-fired power stations will be equipped with CCS (75% in OECD countries). There are different power-generation routes by which CO₂ can be captured in a sufficiently high concentration to make geological storage worthwhile. Integrated Gasification Combined Cycle (IGCC) involves gasifying the coal to produce hydrogen and carbon monoxide for combustion in a combined-cycle gas turbine. This would seem to be the most suitable coal-combustion technology in the long term. Retrofitting of existing coal-fired plants with amine scrubbers and oxy-fuel firing (combustion in an oxygen-rich environment) are the main alternative options. Clarity on the optimal technology will be provided only when demonstration plants have indicated the commercial possibilities, hence the urgent need to construct such plants. In both cases, costs will have to fall rapidly from the current estimated level of $50/tonne CO₂ to the $25/tonne CO₂ assumed in the ACT Scenario. The $25/tonne incentive is assumed to be universal only from 2030 and, as a result, many non-CCS power stations would still be operating in 2050.

Fossil-fuel switching
Fossil-fuel switching (principally from coal to gas, which has lower emissions per KWh) accounts for about 4 Gt CO₂ of the emission reductions. Three principal changes take place under this heading. First, there is the continuation of an existing trend to use more gas in power generation. Gas-generated power increases from 3,225 terawatt hours (TWh) to 7,192 TWh, whereas coal-generated power rises from 6,681 TWh to 8,551 TWh between 2003 and 2050. This trend saves 1.6 Gt CO₂ but is very dependent on the price of natural gas relative to that of coal.

Second, less coal and oil is used by industry in the ACT Scenario while the share of gas increases significantly. Third, there is a strong shift to the greater use of electricity at the expense of all fossil fuels in industry and in buildings. The fact that electricity is produced with fewer emissions in the ACT Scenario thereby results in overall savings.

Fostering a more energy-efficient workplace
Most city-centre office blocks built around the world during the second half of the 20th century are high-rise slabs offering their occupants no fresh air and little or no natural light. They are consequently heavy consumers of energy for air conditioning and lighting.

It took vision and great drive to change all that. Both were provided by Britain’s best-known architect, Sir Norman Foster, whose dream of creating a working environment that enriches employees’ lives as well as benefiting the wider community was first realised in 1974 with a new office park for the insurance company Willis Faber & Dumas in Ipswich, England. That project has won many awards for energy conservation as well as for its straight architectural merits.

Energy efficiency is also one of the virtues of Berlin’s new Reichstag building, which was sensitively and imaginatively redesigned – having been largely destroyed by fire and war – by Foster and his team. It is entirely self-sufficient in this regard, burning only renewable fuels such as rape seed to provide both heating and electricity, and storing excess heat deep underground in summer for extraction in winter.

The best known of Foster and Associates’ many creations in London is 30 St Mary Axe. Popularity known as ‘the Gherkin’, it was commissioned by the global reinsurance company Swiss Re, with a stipulation that energy efficiency should be a major aim. Foster’s team met that requirement with great imagination by designing windows in the 180-metre high, glass-clad building that open and close automatically in response to internal and external electronic signals, and by providing much natural light by having work areas spiral upwards instead of being stacked on top of each other in separate floors.

These energy-saving techniques have subsequently been used by other architects elsewhere in Britain and in Europe. ◆
Renewables
The use of renewables in power generation accounts for about 3 Gt CO$_2$ of the emission reductions in the ACT scenario. Hydro power increases from 2,645 TWh to 4,896 TWh, but this increase is not greatly different to the increase in the IEA’s Baseline Scenario and is constrained by limited site availability. Biomass increases from 210 TWh to 1,430 TWh, but its contribution is limited by the diseconomies of scale arising from biomass-collection costs and competition for land. Wind has the greatest renewable potential, offering a saving of 1.3 Gt CO$_2$, by 2050, but the problem of intermittency limits the proportion of wind-powered generation in any given network. Solar heating and the increased use of biofuels, particularly in transport, are the main renewables contributions to lower non-power-sector carbon emissions.

Nuclear
Surprisingly, the increased use of nuclear power contributes less than 2 Gt CO$_2$ to carbon savings. Nuclear-power generation doubles from the 2003 level in the ACT Scenario but, given that all current capacity will need to be replaced by 2050, a construction of three times today’s capacity over a period of 44 years is implied. The principal constraint suggested in the IEA study on even faster expansion

Long-term vision: the hydrogen economy
Fuel-cell bus taking in hydrogen fuel. Several major European cities have been operating DaimlerChrysler Citaro fuel-cell buses in regular service since 2001. These have now been joined by Beijing and Perth (Australia) including a small number of fuel-cell buses to their public-transport fleet

The movement of electrons to create molecules, or occurring in ionic reactions, produces electricity and heat. If non-carbon elements could produce that energy competitively with that coming from fossil fuels, carbon emissions would be greatly reduced. Vehicles and other machinery using rotating shafts would be powered by batteries, while power stations, jet aircraft and internal-combustion engines could use the heat caused by chemical reaction.

The element most favoured for such technology is hydrogen, because it is highly reactive and abundant. So, too, is oxygen. Bring the two together on a massive global scale and the world’s pollution problems could be largely solved.

It could well happen one day; scientists already talk of the ‘hydrogen economy’. They also warn, though, that much fundamental research is still needed to overcome major problems affecting not only the separation of hydrogen from other elements such as oxygen, but also its transportation, storage, distribution and effective use in chemical reaction. It takes, for example, high temperatures and therefore huge amounts of energy to separate hydrogen from oxygen or out of hydrocarbons such as methane. Energy from renewable sources – heat from a nuclear reactor or electricity generated by hydro- or wind-based technologies – remains far too costly. So scientists are seeking a deeper understanding of the process of photosynthesis through which plants convert carbon dioxide, water and sunlight into hydrogen and oxygen, emitting the latter.

Another problem is the relationship between hydrogen density – which comes down to how many kilometres that can be travelled on a tank of hydrogen that doesn’t weigh a ton – and the temperature needed to allow a feasible rate of electricity production. The greater the density, the higher the temperature.

Nevertheless, the future is already proving practicable and hydrogen/oxygen fuel cells are already powering buses in Europe, China and Australia. ◆
is the continuing high cost of generation", the apparently limited expectations for reducing these costs and the reluctance of private operators to bear the risks (regulatory, safety, waste treatment and storage, decommissioning) associated with nuclear operation. The $25/tonne CO₂ incentive appears insufficient to change this outcome significantly.

The energy supply industry in the ACT Scenario

The principal technologies that would be deployed in the ACT Scenario suggest a carbon-constrained evolution that the energy-supply industry would take in the period to 2050.

1. Coal supply increases by 13%, which results mainly from lower energy-demand growth (as a result of the end-use energy-efficiency improvements) and only to a lesser extent to the substitution of low-carbon fuels for coal.

2. Oil increases by 31%.

3. Gas increases by 67%. As with coal, the principal reason for the modest rate of growth is the lower level of energy demand.

4. Nuclear increases by 102%.

5. Renewables increase by 176%.

Perhaps the most surprising conclusion of the IEA study is that all fossil fuels expand their production in a world where emissions are being managed sufficiently to allow the ultimate stabilisation of atmospheric greenhouse gases at a safe level.

Conclusions

The IEA’s ACT Scenarios demonstrate that a path exists for a climate-stabilising use of energy – even though the full achievement of that goal would happen only in the second half of the century – which is compatible with the growth in wealth and demand for energy services similar to that found in the Baseline Scenario of ‘business as usual’. To achieve this desirable outcome will require, in the IEA’s words, ‘unprecedented co-operation’ between countries and between government and industry. A wide range of policy measures underpins the Scenarios. As well as incentivising voluntary low-carbon choices, governments will often have to restrict private-sector choices, e.g. through mandatory standards. Governments will also have to increase R&D budgets and underwrite the deployment of near-commercial technologies. The IEA draws attention in particular to carbon capture and storage, calling for ‘at least 10 full-scale integrated coal-fired power plants with CCS by 2015’. Underpinning these measures, a fiscal incentive equivalent to $25/tonne CO₂ needs to be put in place in a way that has widespread application and long-term credibility.

To return to the Climate Change Policy Scenarios, only the Strictly Ballroom Scenario provides both the necessary political will and international co-operation that would allow rapid progress towards the adoption of the technology solutions outlined by the IEA. In the absence of one or both of these conditions, technology development and utilisation will be slower, uneven or sometimes stillborn. In the Different Dances Scenario, the establishment of the $25/tonne CO₂ incentive would lack global scope and there would be a continuing pressure for energy-intensive industries to migrate to lower-cost locations. Even where R&D was successful in introducing new technologies, uptake would inevitably be limited without a carbon price and other appropriate incentives. Moreover, the transfer of technologies would be much reduced in a world where the ability to recover the development costs was undermined by disregard for the rights of intellectual property holders. In the Dancing with Wolves and Dirty Dancing Scenarios progress on carbon abatement would be slower yet.

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2 The ACT Scenarios are a family of scenarios; however, all future references will be to the ACT Map Scenario, which is the most wide-ranging member of this family
3 It is not anticipated that all or even most developing countries will have taken measures that will result in a cost of carbon. They will take weaker measures than the industrialised countries. It is possible that the clean development mechanism (CDM) will have a continued existence that will provide an ongoing value for carbon abatement in developing countries
4 This figure is reduced to a negative $0.3 trillion (i.e., a benefit) if the discounted value of the fuel savings in the ACT Scenario is included [p. 60]. These costs exclude those incurred for accelerated R&D and deployment support. These low additional costs are mainly a result of the lower energy demand in the ACT Scenario
5 Oil prices are higher in the Baseline Scenario, with oil rising to $60/bbl in 2050, which is a much greater movement than that which results from the internalisation of the $25/t CO₂ cost. In the ACT Scenario the oil price rises to between $45 and $55/bbl. Coal prices are assumed to remain constant in real terms from 2030
6 The IEA assumes only the spread of efficiency improvements that are already commercially available. Given the limited life-cycle of appliances and motor systems, a fairly rapid conversion of the stock is projected
7 Between $0.02-$0.03/KWh at a 5% discount rate and $0.03-$0.06/KWh at a 10% discount rate
ENERGY EFFICIENCY
ANGLO LEARNS A NEW BALL GAME
IAN LANGRIDGE
CONSIDERING the warnings provided by the 1973 and 1979 oil-price crises, it took industrialists a surprisingly long time to take seriously the need to improve the energy efficiency of their operations. They began to do so only a few years ago, due largely to government pressure on them which was in turn driven by studies showing clearly that man is steadily degrading planet earth through the production and release into the atmosphere of a range of greenhouse gases (GHGs) – mainly CO$_2$, hydrofluorocarbons, and nitrous oxides.

At last, the warnings are heeded

The largest and most comprehensive of those studies was published in 2001 by the Intergovernmental Panel on Climate Change (IPCC) – now finalising its Fourth Assessment Report, Climate Change 2007. The IPCC is a United Nations (UN) body created in 1988 to assess published data on climate change, and how far understanding of the subject has progressed. Before that study was published, governments had been slow to accept responsibility for compelling better use of carbon-based energy resources in order to prevent further climate deterioration. The basic terms of the Kyoto Protocol, an amendment to the UN Framework Convention on Climate Change that was adopted at the Earth Summit in Rio de Janeiro in 1992, were not agreed until 1997.

To achieve its core aim, the Protocol required two conditions to be met for it to come into force. First, at least 55% of the world’s major producers of GHGs, referred to as the developed countries, would have to accept its terms. Second, developed countries accepting those terms would, between them, have to account for at least 55% of developed countries’ total emissions in 1990 of GHGs. The first requirement was achieved only in May 2002, and it took close on a further three years for the second condition to be met, when Russia came to the party.

The target set by the Protocol for the developed countries signing it was a tough one. Though it varied from country to country, it averaged out to reducing emissions of GHGs over the period 2008-2012 to a level that would be 5% below their 1990 level of such emissions. It was estimated that, to achieve that target, some countries would probably have to reduce the level of their 2008 emissions by 15%. Clearly, that would not be achieved without compelling legislation being passed by the governments of those countries.

Energy- and carbon-emissions-reduction targets

Developed countries began to impose their own-energy-consumption-reduction targets and started to understand the magnitude of what is required to meet them. This is most evident in the EU, which has its own emissions-trading scheme (ETS). Meanwhile, even though no targets were set for them as developing countries, South Africa and a number of other nations began to pursue voluntary energy-consumption-reduction targets in manufacturing and other sectors. In South Africa’s case, the government announced that its manufacturing sector would have to have reduced its energy consumption to a level that would be 12% below that of 2003 by 2014, with the mining sector 15% below its 2003 level. Industry representatives pointed out the need for a qualification to allow for energy consumption to be related to the level of volume output. The aim should not be a simplistic reduction in energy consumption, but more efficient use of energy if the private sector were to be allowed to exploit global business opportunities on which a higher rate of economic growth depended. The desired
Using electricity instead of compressed air or diesel fuel as an energy source is one of the ways in which Anglo American’s South African mines have become more energy-efficient.

Ore in some underground mines has to be blasted so that chunks of it can be carried to the surface for processing. The holes into which explosive is placed have until recently been drilled by equipment using compressed air. That has several major disadvantages.

First, the compressed air will usually have to travel considerable distances from the compressor to the stope face where the drills are being used. That distance, holes in the piping and conversion of energy from one form of use (compression) to another (impact) reduces the amount of energy with which the drill strikes and drills into the rock. Generally, no more than 3% of the energy used to compress the air is available to the drill bit. Sometimes the percentage falls to a level that brings drilling to a halt.

The drills are also exhausting to use because of the noise and vibration their operation produces. In other words, they also consume much human energy.

A number of South African mines, including mines in the Anglo American Group, have therefore abandoned their compressed-air drills in favour of the Swiss-owned Hilti electric rock drill. Designed specifically for deep-level mining conditions, the TE MD 20 drill is 98% efficient, which is to say that, regardless of how far it is from the source of its power, only 2% of that power is lost. Its operation also produces far less noise and vibration than compressed-air drills.

Finally, electricity is a cheaper form of energy than compressed air, and its supply is far more reliable than that of compressed air.

The drill has not yet been found superior to compressed-air drills under all mining conditions. Nevertheless, well over 2,000 of them are being used in South African mines. ☞
focus of government policy, legislation and industrial practice should therefore be energy efficiency, rather than absolute energy consumption – at least to begin with.

Energy efficiency was not a new idea to industrialists, even if most of them hadn't as yet paid it serious attention. It offered the opportunity of gaining a strategic advantage over competitors; of enjoying greater volume sales and better returns on output. If industrialists had not yet demonstrated particular concern over energy efficiency, it was because in many parts of the world energy had been cheap. In labour-intensive mining it still accounts for less than 10% of total production costs, though considerably more in highly automated industries such as pulp and paper.

By contrast, the Scandinavian countries, which in general are fairly heavily dependent on imported energy and therefore pay dearly for it, had shown that substantial financial gains could be won by smart use of energy. In Scandinavia and parts of northern Europe, heat used in the generation of electricity also heats water that is pumped to factories and homes. In Sweden, the Scandic hotel group found its profits rising significantly as it found ways to use energy more efficiently.

While the Scandinavian countries were showing the way, industrial companies around the world were also awakening to the need to operate in ways that were environmentally sound. ‘Sustainable development' became an important guiding principle, and regular reporting on energy as part of a comprehensive response to sustainable development issues, became a necessary part of industrial companies' annual reports. But while those reports detailed efforts to control GHGs and avoid other forms of pollution, they rarely made mention of improving the efficiency of energy usage. The Anglo American Group's experience of trying to achieve improvement in that area helps explain why.

**Rocky Mountain Institute arrives at Anglo**

The Anglo experience began in 2003 with an invitation from Anglo to the US-based Rocky Mountain Institute (RMI) to visit its operations in South Africa and advise on ways to improve their energy usage. RMI was formed in 1982 by a physicist, Amory Lovens, who has been described as an 'energy visionary'. The aim of the organisation is to find and recommend ways to use resources more efficiently. RMI's research & consulting team provide knowledge of advanced technologies and techniques across a range of disciplines in an analytical and imaginative approach to devising cost-effective solutions.

Lovens arrived with his team in 2003. Their first task was to determine the level of Anglo American operations' energy consumption – and how it was divided between electricity, coal and fuels – and the level of carbon emissions from that consumption. The figure they produced was, they observed, about equal to Finland's or Chile's entire energy consumption, which indicated the potential for saving substantial energy costs.

They therefore examined several Anglo plants closely, identifying opportunities for significantly improving energy efficiency and discussing them with those working at the operations. The aim was to stimulate out-of-the-box thinking by Anglo's plant operators, and it succeeded. Over the following years a number of technical innovations made energy consumption at those plants more efficient.

**Changing Anglo's energy mindset**

Although progress in certain areas of the Group's operations has been patchy, steady progress overall has been made in the energy-efficiency field since the arrival of Lovens and his team four years ago. Experience to date suggests that creating a mindset open to improving energy efficiency is at least as important as focusing on specific energy-efficiency projects. This is a key task for Anglo's energy-efficiency managers in South Africa, South America, Australia and the UK. The task of the energy-efficiency managers is, in short, to bring about a culture change throughout the Group – one that places energy efficiency high up the list of operating priorities, along with safety and protection of the environment.

The first requirement in the quest for greater energy efficiency is to quantify exactly how much energy in its various forms is being consumed by each operation, and how much output is being produced at that level of energy consumption. That is not a complicated task at fixed installations such as the pulp and paper mills that until recently
formed a significant part of the Group, and the motivation to do it properly is, as already observed, provided by the relatively high proportion of total operating costs accounted for by energy in its various forms.

By contrast, recording energy consumption has not traditionally been high on the list of operational requirements at many of the Group’s mines because energy has not accounted for a major proportion of their total operating costs – especially in South Africa. Part of the reason is that South Africa still enjoys some of the world’s cheapest electricity, has relatively cheap coal of its own and produces fuels from imported crude oil and from its own coal. This, though, is set to change as new generating capacity is built and costs rise.

Measurement is key, and determining Group-wide effective measurement techniques, relevant across varying commodities and geographies, represents one of the biggest challenges.

Notwithstanding today’s much higher metal prices, energy is increasingly a principal determining factor in deciding whether to proceed with a new mining project or not. Expansions in South America and South Africa are going to be particularly affected by increasing costs of energy consequent on new

Methane: not given an airing

Coal mines, whether active or abandoned, are a significant source of methane, a gas that is a by-product of coal formation. Natural gas, a valuable source of energy, is about 90% methane, yet it is only in recent years that projects have been launched around the world to capture methane from coal mines’ ventilation systems so that it can be used to produce electricity or fire boilers, or serve as a feedstock for the production of a range of industrial products.

The US leads the way in this development, followed by Australia, where projects to use coal mine methane as an energy source, rather than release it into the environment, are financially supported by the federal government’s A$400 million (c. US$340 million) Greenhouse Gas Abatement Programme. These projects are located in New South Wales and Queensland.

Anglo Coal Australia (ACA) owns several mines in Queensland. They sell methane, either to an independent organisation that uses it to generate electricity at a power station alongside the mine producing the methane, or to Queensland State Gas, which pipes it through its 627 kilometre-long grid to customers.

Having electricity generated close to where it is used avoids the loss of power that occurs when electricity has to be transmitted over long distances (the loss is in the form of heat along the transmission line). That loss had been costing the ACA mine that now enjoys on-site power generation A$1.5 million a year.

There is, too, a major environmental benefit from using methane for electricity generation rather than venting or flaring it. Combusting it produces water and carbon dioxide, and the latter is 21 times less harmful in its greenhouse effect than methane. Using methane rather than coal to provide energy for power generation also avoids producing emissions of nitrogen oxides and sulphur dioxide.

Anglo Coal’s German Creek coal mine in Australia is both improving safety and benefiting the environment by capturing methane and selling it to the local pipeline network. Extracted from coal seams in advance of mining, the gas provides enough energy to power around 16,000 homes.
investments in generating capacity that are in the process of being made.

In these changed circumstances, where the price of a single major input could make the difference between a new project’s being given the go-ahead or remaining on the drawing-board, the price of energy assumes much greater importance. A lack of historical data indicating the energy consumption and efficiency of different mining techniques and equipment is an impediment, but this will improve with more focus on the subject over time.

If the first step in improving energy efficiency is to record energy consumption accurately and in considerable detail, the second is to ensure that equipment is being used solely for the purpose for which it was designed. That is the responsibility of operations managers. The third step is to seek improvements in equipment design, and to the ways in which equipment is used.

Design improvements are most likely to be achieved if there is good two-way communication between designers and end-users. The operating experience of employees and contractors at the ‘sharp end’ of things will make them more knowledgeable than anyone else about any piece of equipment’s functional shortcomings, and

Anglo Chile turns the spotlight on energy efficiency

Anglo Chile recently distributed 30,000 low-energy lightbulbs to its employees and communities near its operations. The campaign formed part of Anglo Chile’s Energy Efficiency Programme, which aims to increase the energy efficiency of its operations by 15% by 2014. This kind of lightbulb consumes up to 80% less energy than a regular bulb and the Anglo Chile initiative was intended to raise awareness of its potential.

A public event, attended by Chile’s Minister of Mines Karen Poniachik, was held in July to launch the initiative at Anglo Base Metals’ Chagres smelter. After the ceremony, 60 students from the local school distributed the lightbulbs to around 4,400 homes in Catemu, Llay-Llay and Panquehue, three small towns located near to the smelter.

Anglo Chile’s Energy Efficiency Programme was launched in 2004 and as well as aiming to improve energy efficiency by 15%, it further aims to reduce CO\textsubscript{2} emissions by 10%. Anglo Chile has undertaken several initiatives as part of the programme, including:

- an internal communications campaign to motivate employees to reduce their energy consumption;
- an agreement with Honda to promote the use of hybrid cars;
- a mining round table where mining companies shared experiences and best practice on the issue;
- the current promotion of low-energy lightbulbs.

Anglo Chile received the 2006 National Energy Efficiency Prize awarded by Chile’s Ministry of Economics in recognition of its efforts and leadership in this field.
renders them best placed to produce ideas on how to redesign the equipment to achieve greater energy efficiency. But end-users have to be encouraged to make comments on equipment’s performance – which they cannot do if they have not calculated its energy efficiency – and to offer ideas for improving its design and operation.

That is why the number of working groups throughout Anglo American has been substantially increased during the past two years, all of them now charged with finding ways to operate equipment such as air compressors, pumps, electric motors, lighting, etc. in ways that improve energy efficiency. The challenge facing Anglo’s energy-efficiency managers is to ensure that those groups remain stimulated and share their knowledge and ideas with each other so that intellectual cross-pollination occurs.

That knowledge will, of course, need to influence equipment-buying decisions. Our next challenge, therefore, is to ensure that Anglo’s capital-project teams are informed of developments and changes so that they can factor the importance of improving energy efficiency into purchasing decisions for new equipment.

For information and ideas about equipment design, best operational usage and innovations in both those areas to be shared effectively between all interested parties in the Anglo American Group, a well-structured information system is required. Work is under way to utilise best practice drawn from companies in other sectors to build and tailor a system suitable to Anglo’s requirements.

The idea of culture change referred to earlier in the article has to be extended to equipment designers and manufacturers, to stimulate them to achieve greater energy efficiency in their products. Anglo Platinum, for example, has introduced extra low profile (XLP) equipment in some of its underground mines. Results from three pilot sites have shown an increase in mining efficiency, and it is intended to transfer the technological benefits gained on the job to the equipment manufacturers. What we are trying to prove is that there doesn't have to be a net cost to making consumption of energy more efficient. It comes down to attitude, to thinking more consciously of the financial cost of using energy inefficiently, let alone plain wastefully, and acting to redress it by redesigning equipment, using it in a more energy-efficient way and... well, by turning off the lights when they are not needed.

Are we getting the message across? Not yet to the extent we need to. There have been some satisfying improvements in our use of energy, but we have to market them across the entire Group, and those contracted to our operations, so that people are inspired to produce and offer their own ideas for saving energy or reducing GHGs, as they do in other operational aspects.

Importantly, Anglo has now committed to extending its activities in response to mechanisms available under international agreements such as the Kyoto Protocol. The Clean Development Mechanism (CDM) permits carbon credits to be earned in developing countries. After the successful development of three CDM projects in Anglo, a renewed push to identify efficiency projects that yield carbon-emissions benefits is now also under way.

**Looking further ahead**

Since 2003, when an Anglo American Group-wide energy-efficiency training programme and a pilot project were conducted, there has been an increasing focus on efficiency, the cost of energy and the reduction of carbon emissions. We are planning an overall improvement in our energy efficiency of 15% by 2014 – by which time the Group plans to have reduced the amount of carbon produced per unit of output by 10%. In Australia, to cite just one example, our two methane-capture-and-power-generation projects at Anglo Coal operations in Queensland between them are achieving GHG savings equivalent to removing 375,000 cars from the roads.

Further out, Anglo American is hoping to have achieved a substantial improvement in the Group’s energy efficiency, and to have made significant inroads in reducing carbon emissions, by the middle of the century. We have gained considerable knowledge in recent years and we now have the structures in place to do this.

Meeting the targets we have set ourselves will need additional focus, more resources and a commitment from leadership at all levels to prioritise energy-efficiency improvement and carbon-emissions reduction.
The increasingly prosperous western world produces vast amounts of waste. Every year Britons chuck out over 900,000 tonnes of electrical and electronic goods, among them 8 million large domestic appliances. Toronto’s residents produce so much household waste that 1 million tonnes of it have to be sent annually across the border to Michigan for processing.

Such levels of waste might seem unsustainable. The energy, mostly derived from non-renewable fossil fuels, that went into producing and distributing the jettisoned items is irretrievably lost, even if their materials aren’t. There are serious concerns voiced by environmentalists, too, about methods used to dispose of waste.

Fortunately, techniques have been developed in recent years that help reassure environmentalists. Those techniques also produce energy gains from waste. Waste was, and often still is, merely buried in landfill sites. Since the sites are, to minimise waste-transportation costs, located not far from the residential or industrial areas, they occupy land which increases in value as industrial or residential areas expand towards it. Landfill sites, however, remain unstable and therefore unsuitable for building purposes long after they are full. In the meantime, organic waste deposited in them decomposes to form methane and carbon dioxide (CO$_2$), which escape into the air unless they are captured.

Modern techniques have succeeded to a significant degree in achieving that capture. The heat obtained from igniting the methane is used to generate electricity or to fire boilers and kilns. For example, two financially viable, methane-combusting power plants near Paris each produce 85 million kilowatt hours (kWh) annually, or enough to meet the needs of more than 30,000 people, from methane produced by a landfill site that annually receives the waste of 2 million people.

Combusting methane produces global-warming CO$_2$. The latter, however, has many uses, from carbonating drinks to acting as a compression gas in various kinds of equipment. Landfill sites are, nevertheless, still regarded as the worst way of dealing with any kind of waste. Re-using products or recycling their materials, though not without challenges, wins most approval from governments, followed by incineration. The latter provides more energy than it consumes because of the calorific value contained in many materials that get incinerated. The latest incineration techniques also reduce to harmless levels the emission of dangerous substances such as dioxins. As a result, Sweden, which is highly conscientious about environmental management, has rapidly increased the number of its waste-incineration plants to about 30, and obtains more than twice the amount of energy from them than waste incineration provided a couple of decades ago.

Many materials found in household and industrial waste, such as solvents, paint residues, oils, wood chips and tyres, also get incinerated in cement kilns to reduce consumption of non-renewable energy sources. Temperatures far higher than those produced in incinerators destroy hazardous materials, alkaline limestone counters acidity found in some materials, and clinker – a fusion of cement’s raw materials – absorbs heavy metals. China plans to have 30% of its energy needs coming from solid waste by 2030. Technically that target looks possible. But it might be missed because rapidly spreading prosperity is producing western levels of waste. ◆
Anti-nuclear activists try to prevent a transport of highly radioactive spent fuel rods getting through to a nuclear-waste storage facility at Gorleben in Germany. The anti-nuclear movement is especially strong in Germany and is demanding that all of the country’s 19 nuclear reactors be closed down. In contrast, next-door neighbour France quietly goes about its business of generating around 80% of the country’s electricity requirements from near-emissions-free nuclear power stations.

A threefold expansion of nuclear power could contribute significantly to staving off climate change by avoiding 1 billion to 2 billion tons of carbon emissions annually.
NUCLEAR POWER supplies a sixth of the world’s electricity. Along with hydropower (which supplies slightly more than a sixth), it is the major source of ‘carbon-free’ energy today. The technology suffered growing pains, seared into the public’s mind by the Chernobyl and Three Mile Island accidents, but plants have demonstrated remarkable reliability and efficiency recently. The world’s ample supply of uranium could fuel a much larger fleet of reactors than exists today throughout their 40- to 50-year lifespan.

With growing worries about global warming and the associated likelihood that greenhouse gas emissions will be regulated in some fashion, it is not surprising that governments and power providers in the US and elsewhere are increasingly considering building a substantial number of additional nuclear power plants. The fossil-fuel alternatives have their drawbacks. Natural gas is attractive in a carbon-constrained world because it has lower carbon content relative to other fossil fuels and because advanced power plants have low capital costs. But the cost of the electricity produced is very sensitive to natural gas prices, which have become much higher and more volatile in recent years. In contrast, coal prices are relatively low and stable, but coal is the most carbon-intensive source of electricity. The capture and sequestration of carbon dioxide, which will add significantly to the
cost, must be demonstrated and introduced on a large scale if coal-powered electricity is to expand significantly without emitting unacceptable quantities of carbon into the atmosphere. These concerns raise doubts about new investments in gas- or coal-powered plants.

All of which points to a possible nuclear revival. And indeed, more than 20,000 megawatts of nuclear capacity have come online globally since 2000, mostly in the Far East. Yet despite the evident interest among major nuclear operators, no firm orders have been placed in the US. Key impediments to new nuclear construction are high capital costs and the uncertainty surrounding nuclear waste management. In addition, global expansion of nuclear power has raised concerns that nuclear weapons ambitions in certain countries may inadvertently be advanced.

In 2003 we co-chaired a major Massachusetts Institute of Technology (MIT) study, *The Future of Nuclear Power*, that analyzed what would be required to retain the nuclear option. That study described a scenario whereby worldwide nuclear power generation could triple to 1 million megawatts by the year 2050, saving the globe from emissions of between 0.8 billion and 1.8 billion tons of carbon a year, depending on whether gas- or coal-powered plants were displaced. At this scale, nuclear power would significantly contribute to the stabilization of greenhouse gas emissions, which requires about 7 billion tons of carbon to be averted annually by 2050.

**The fuel cycle**

If nuclear power is to expand by such an extent, what kind of nuclear plants should be built?

A chief consideration is the fuel cycle, which can be either open or closed. In an open fuel cycle, also known as a once-through cycle, the uranium is ‘burned’ once in a reactor, and spent fuel is stored in geologic repositories. The spent fuel includes plutonium that could be chemically extracted and turned into fuel for use in another nuclear plant. Doing that results in a closed fuel cycle, which some people advocate.

Some countries, most notably France, currently use a closed fuel cycle in which plutonium is separated from the spent fuel and a mixture of plutonium and uranium oxides is subsequently burned again. A longer-term option could involve recycling all the transuranics (plutonium is one example of a transuranic element), perhaps in a so-called fast reactor. In this approach, nearly all the very long-lived components of the waste are eliminated, thereby transforming the nuclear waste debate. Substantial research and development is needed, however, to work through daunting technical and economic challenges to making this scheme work.

Recycling waste for re-use in a closed cycle might seem like a no-brainer: less raw material is used for the same total power output, and the
problem of long-term storage of waste is alleviated because a smaller amount of radioactive material must be stored for many thousands of years. Nevertheless, we believe that an open cycle is to be preferred over the next several decades. First, the recycled fuel is more expensive than the original uranium. Second, there appears to be ample uranium at reasonable cost to sustain the tripling in global nuclear power generation that we envisage with a once-through fuel cycle for the entire lifetime of the nuclear fleet (about 40 to 50 years for each plant). Third, the environmental benefit for long-term waste storage is offset by near-term risks to the environment from the complex and highly dangerous reprocessing and fuel-fabrication operations. Finally, the reprocessing that occurs in a closed fuel cycle produces plutonium that can be diverted for use in nuclear weapons.

The type of reactor that will continue to dominate for at least two decades, probably longer, is the light-water reactor, which uses ordinary water (as opposed to heavy water, containing deuterium) as the coolant and moderator. The vast majority of plants in operation in the world today are of this type, making it a mature, well-understood technology.

Reactor designs are divided into generations. The earliest prototype reactors, built in the 1950s and early 1960s, were often one of a kind. Generation II reactors, in contrast, were commercial designs built in large numbers from the late 1960s to the early 1990s. Generation III reactors incorporate design improvements such as better fuel technology and passive safety, meaning that in the case of an accident the reactor shuts itself down without requiring the operators to intervene. The first generation III reactor was built in Japan in 1996. Generation IV reactors are new designs that are currently being researched, such as pebble-bed reactors and lead-cooled fast reactors. In addition, generation III+ reactors are designs similar to generation III but with the advanced features further evolved. With the possible exception of high-temperature gas reactors (the pebble bed is one example), generation IV reactors are several decades away from being candidates for significant commercial deployment. To evaluate our scenario through to 2050, we envisaged the building of generation III+ light-water reactors.

The pebble-bed modular reactor introduces the interesting prospect of modular nuclear plants. Instead of building a massive 1,000-megawatt plant, modules each producing around 100 megawatts can be built. This approach may be particularly attractive, both in developing countries and in deregulated industrial countries, because of the much lower capital costs involved. The traditional large plants do have the advantage of economy of scale, most likely resulting in lower cost per kilowatt of capacity, but this edge could be challenged if efficient factory-style production of large numbers of modules could be implemented. South Africa is scheduled to begin construction of a 110-megawatt demonstration pebble-bed plant in 2007, to be completed by 2011, with commercial modules of about 165 megawatts planned for 2013. The hope is to sell modules internationally, in particular throughout Africa.

**Reducing costs**

Based on previous experience, electricity from new nuclear power plants is currently more expensive than that from new coal- or gas-powered plants. The 2003 MIT study estimated that new light-water reactors would produce electricity at a cost of 6.7 cents per kilowatt-hour. That figure includes all the costs of a plant, spread over its lifespan, and includes items such as an acceptable return to investors. In comparison, under equivalent assumptions we estimated that a new coal plant would produce electricity at a cost of 4.2 cents per kilowatt-hour. For a new gas-powered plant, the cost is very sensitive to the price of natural gas and would be about 5.8 cents per kilowatt-hour for today’s high gas prices (about $7 per million British thermal units (Btu)).

Some people will be skeptical about how well the cost of nuclear power can be estimated, given past over-optimism, going back to claims in the early days that nuclear power would be “too cheap to meter”. But the MIT analysis is grounded in past experience and actual performance of existing plants, not in promises from the nuclear industry. Some might also question the uncertainties inherent in such cost projections. The important point is that the
estimates place the three alternatives – nuclear, coal and gas – on a level playing field, and there is no reason to expect unanticipated contingencies to favor one over the other. Furthermore, when utilities are deciding what kind of power plant to build, they will base their decisions on such estimates.

Several steps could reduce the cost of the nuclear option below our baseline figure of 6.7 cents per kilowatt-hour. A 25% reduction in construction expenses would bring the cost of electricity down to 5.5 cents per kilowatt-hour. Reducing the construction time of a plant from five to four years and improvements in operation and maintenance can shave off a further 0.4 cent per kilowatt-hour. How any plant is financed can depend dramatically on what regulations govern the plant site. Reducing the cost of capital for a nuclear plant to be the same as for a gas or coal plant would close the gap with coal (4.2 cents per kilowatt-hour). All these reductions in the cost of nuclear power are plausible – particularly if the industry builds a large number of just a few standardized designs – but not yet proved.

Nuclear power becomes distinctly favored economically if carbon emissions are priced. We will refer to this as a carbon tax, but the pricing mechanism need not be in the form of a tax. Europe has a system in which permits to emit carbon are traded on an open market. In early 2006 permits were selling for more than $100 per tonne of carbon (or $27 per tonne of carbon dioxide), although recently their price has fallen to about half that. (A metric unit 1 tonne is equal to 1.1 US tons.) A tax of only $50 per tonne of carbon raises coal-powered electricity to 5.4 cents per kilowatt-hour. At $200 per tonne of carbon, coal reaches a whopping 9.0 cents per kilowatt-hour. Gas fares much better than coal, increasing to 7.9 cents per kilowatt-hour under a $200 tax. Fossil-fuel plants could avoid the putative carbon tax by capturing and sequestering the carbon, but the cost of doing that contributes in the same way that a tax would.

Because it is many years since construction of a nuclear plant was embarked on in the US, the companies that build the first few new plants will face extra expenses that subsequent operators will not have to bear, along with additional risk in working through a new licensing process. To help...
overcome that hurdle, the Energy Policy Act of 2005 included a number of important provisions, such as a tax credit of 1.8 cents per kilowatt-hour to new nuclear plants for their first eight years of operation. The credit, sometimes called a first-mover incentive, applies to the first 6,000 megawatts of new plants to come online. Several consortiums have formed to take advantage of the new incentives.

Waste management
The second big obstacle that a nuclear renaissance faces is the problem of waste management. No country in the world has yet implemented a system for permanently disposing of the spent fuel and other radioactive waste produced by nuclear power plants. The most widely favored approach is geologic disposal, in which waste is stored in chambers hundreds of meters underground. The goal is to prevent leakage of the waste for many millennia through a combination of engineered barriers (for example, the waste containers) and geologic ones (the natural rock structure where the chamber has been excavated and the favorable characteristics of the hydrogeologic basin). Decades of studies support the geologic disposal option. Scientists have a good understanding of the processes and events that could transport radionuclides from the repository to the biosphere. Despite this scientific confidence, the process of approving a geologic site remains fraught with difficulties.
A prime case in point is the proposed facility at Yucca Mountain in Nevada, which has been under consideration for two decades. Recently the site was found to have considerably more water than anticipated. It remains uncertain whether the Nuclear Regulatory Commission (NRC) will license the site.

Delays in resolving waste management (even if it is approved, it is unlikely that Yucca Mountain will be accepting waste before 2015) may complicate efforts to construct new power plants. By law, the government was to begin moving spent fuel from reactor sites to a repository by 1998. Failure to do so has led to a need for increased local storage at many sites and associated unhappiness among neighbors, towns and states.

Perhaps the first country to build a permanent storage site for its high-level nuclear waste will be Finland. At Olkiluoto, the location of two nuclear reactors, excavation has begun on an underground research facility called Onkalo. Extending about half a kilometer underground, the Onkalo project will involve study of the rock structure and groundwater flows and will test the disposal technology in actual deep underground conditions. If all goes according to plan and the necessary government licenses are obtained, the first canisters of waste could be emplaced in 2020. By 2130 the repository would be complete, and the access routes would be filled and sealed. The money to pay for the facility has been levied on the price of Finnish nuclear power since the late 1970s.

To address the waste management problem in the US, the government should take title to the spent fuel stored at commercial reactor sites across the country and consolidate it at one or more federal interim storage sites until a permanent disposal facility is built. The waste can be temporarily stored safely and securely for an extended period. Such extended temporary storage, perhaps even for as long as 100 years, should be an integral part of the disposal strategy. Among other benefits, it would take the pressure off government and industry to come up with a hasty disposal solution.

Meanwhile the Department of Energy should not abandon Yucca Mountain. Instead it should reassess the suitability of the site under various conditions and modify the project’s schedule as needed. If nuclear power expanded globally to one million megawatts, enough high-level waste and spent fuel would be generated in the open fuel cycle to fill a Yucca Mountain-size facility every three and a half years. In the court of public opinion, that fact is a significant disincentive to the expansion of nuclear power, yet it is a problem that can and must be solved.

The threat of proliferation

In conjunction with the domestic program of waste management just outlined, the president should continue the diplomatic effort to create an international system of fuel supplier countries and user countries. Supplier countries such as the US, Russia, France and the UK would sell fresh fuel to user countries with smaller nuclear programs and commit to removing the spent fuel from them. In return, the user countries would forgo the construction of fuel-producing facilities. This

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**Tackling the climate change problem**

The Wedge Concept

![Diagram](https://example.com/diagram.png)

In between the two emissions paths is the “stabilisation triangle.” It represents the total emissions cut that climate-friendly technologies must achieve in the coming 50 years.

The stabilisation triangle can be divided into seven “wedges”, each a reduction of 25 million tons of carbon emissions over 50 years. The wedge has proved to be a useful unit because its size and time frame match what specific technologies can achieve. Many combinations of technologies will fill the seven wedges.

Source: Robert H Socolow and Stephen W Pacala
arrangement would greatly alleviate the danger of nuclear weapons proliferation because the chief risks for proliferation involve not the nuclear power plants themselves but the fuel-enrichment and reprocessing plants. The current situation with Iran’s uranium enrichment program is a prime example. A scheme in which fuel is leased to users is a necessity in a world where nuclear power is to expand threefold, because such an expansion will inevitably involve the spread of nuclear power plants to some countries of proliferation concern.

A key to making the approach work is that producing fuel does not make economic sense for small nuclear power programs. This fact underlies the marketplace reality that the world is already divided into supplier and user countries. Instituting the supplier/user model is largely a matter, albeit not a simple one, of formalizing the current situation more permanently through new agreements that reinforce commercial realities.

Although the proposed regime is inherently attractive to user nations – they get an assured supply of cheap fuel and are relieved of the problem of dealing with waste materials – other incentives should also be put in place because the user states would be agreeing to go beyond the requirements of the treaty on the non-proliferation of nuclear weapons. For example, if a global system of tradable carbon credits were instituted, user nations adhering to the fuel-leasing rules could be granted credits for their new nuclear power plants.

Iran is the most obvious example today of a nation that the global community would rather see as a ‘user state’ than as a producer of enriched uranium. But it is not the only difficult case. Another nation whose program must be addressed promptly is Brazil, where an enrichment facility is under construction supposedly to provide fuel for the country’s two nuclear reactors. A consistent approach to countries such as Iran and Brazil will be needed if nuclear power is to be expanded globally without exacerbating proliferation concerns.

The terawatt future

A terawatt – 1 million megawatts – of ‘carbon-free’ power is the scale needed to make a significant dent in projected carbon dioxide emissions at mid-century. In the terms used by Socolow and Pacala, that contribution would correspond to one to two of the seven required ‘stabilization wedges’. Reaching a terawatt of nuclear power by 2050 is certainly challenging, requiring deployment of about 2,000 megawatts a month. A capital investment of $2 trillion over several decades is called for, and power plant cost reduction, nuclear waste management and a proliferation-resistant international fuel cycle regime must all be addressed aggressively over the next decade or so. A critical determinant will be the degree to which carbon dioxide emissions from fossil-fuel use are priced, both in the industrial world and in the large emerging economies such as China, India and Brazil.

The economics of nuclear power are not the only factor governing its future use. Public acceptance also turns on issues of safety and nuclear waste, and the future of nuclear power in the US and much of Europe remains in question. Regarding safety, it is essential that NRC regulations are enforced diligently, which has not always been the case.

In the scenario developed as part of the MIT study, it emerged that the US would approximately triple its nuclear deployment – to about 300,000 megawatts – if a terawatt were to be realized globally. The credibility of such a scenario will be largely determined in the forthcoming decade by the degree to which the first-mover incentives in the 2005 Energy Policy Act are exercised, by the capability of the government to start moving spent fuel from reactor sites and by whether the American political process results in a climate change policy that will significantly limit carbon dioxide emissions.

THE AUTHORS
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1 A Plan to Keep Carbon in Check, by Robert H Socolow and Stephen W Pacala; Scientific American, September 2006
2 Smarter Use of Nuclear Waste, by William H Hannum, Gerald E Marsh and George S Stanford; Scientific American, December 2005
3 Next-Generation Nuclear Power, by James A Lake, Ralph G Bennett and John F Kotek; Scientific American, January 2002
4 Since this article was written these dates have changed to 2009, 2013 and 2016, respectively
5 Can We Bury Global Warming?, by Robert H Socolow; Scientific American, July 2005
6 US Nuclear Regulatory Commission

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Solar cells, wind turbines and biofuels are poised to become major energy sources. New policies could dramatically accelerate that evolution.

The Rise of Renewable Energy

Daniel M Kammen
Renewable energy technologies were suddenly and briefly fashionable three decades ago in response to the oil embargoes of the 1970s, but the interest and support were not sustained. In recent years, however, dramatic improvements in the performance and affordability of solar cells, wind turbines and biofuels – ethanol and other fuels derived from plants – have paved the way for mass commercialization. In addition to their environmental benefits, renewable sources promise to enhance America’s energy security by reducing the country’s reliance on fossil fuels from other nations. What is more, high and wildly fluctuating prices for oil and natural gas have made renewable alternatives more appealing.

We are now in an era where the opportunities for renewable energy are unprecedented, making this the ideal time to advance clean power for decades to come. But the endeavor will require a long-term investment of scientific, economic and political resources. Policymakers and ordinary citizens must demand action and challenge one another to hasten the transition.

Let the sun shine

Solar cells, also known as photovoltaics, use semiconductor materials to convert sunlight into electric current. They now provide just a tiny slice of the world’s electricity: their global generating capacity of 5,000 megawatts (MW) is only 0.15% of the total generating capacity from all sources. Yet sunlight could potentially supply 5,000 times as much energy as the world currently consumes. And thanks to technology improvements, cost declines and favorable policies in many states and nations, the annual production of photovoltaics has increased by more than 25% a year for the past decade and by a remarkable 45% in 2005. The cells manufactured in 2005 added 1,727 MW to worldwide generating capacity, with 833 MW made in Japan, 353 MW in Germany and 153 MW in the US.

Solar cells can now be made from a range of materials, from the traditional multicrystalline silicon wafers that still dominate the market to thin-film silicon cells and devices composed of plastic or organic semiconductors. Thin-film photovoltaics are cheaper to produce than crystalline silicon cells but are also less efficient at turning light into power. In laboratory tests, crystalline cells have achieved efficiencies of 30% or more; current commercial cells of this type range from 15% to 20%. Both laboratory and commercial efficiencies for all kinds of solar cells have risen steadily in recent years, indicating that an expansion of research efforts would further enhance the performance of solar cells on the market.

Solar photovoltaics are particularly easy to use because they can be installed in so many places – on the roofs or walls of homes and office buildings, in vast arrays in the desert, even sewn into clothing to power portable electronic devices. The state of California has joined Japan and Germany in leading a global push for solar installations: the ‘Million

Previous page: “Biomass, the use of crops to produce energy for use in the power generation, transport, industry and buildings sectors, could yield significant emissions savings... The extent to which biomass can be produced sustainably and cost-effectively will depend on development in lignocellulosic technology and to what extent marginal and low-quality land is used for growing crops.” The Economics of Climate Change: The Stern Review
Solar Roof’ commitment is intended to create 3,000 MW of new generating capacity in the state by 2018. Studies done by my research group, the Renewable and Appropriate Energy Laboratory at the University of California, Berkeley, show that annual production of solar photovoltaics in the US alone could grow to 10,000 MW in just 20 years if current trends continue.

The biggest challenge will be lowering the price of the photovoltaics, which are now relatively expensive to manufacture. Electricity produced by crystalline cells has a total cost of 20 to 25 cents per kilowatt-hour, compared with four to six cents for coal-fired electricity, five to seven cents for power produced by burning natural gas, and six to nine cents for biomass power plants. (The cost of nuclear power is harder to pin down because experts disagree on which expenses to include in the analysis; the estimated range is two to 12 cents per kilowatt-hour.) Fortunately, the prices of solar cells have fallen consistently over the past decade, largely because of improvements in manufacturing processes. In Japan, where 290 MW of solar generating capacity were added in 2005 and an even larger amount was exported, the cost of photovoltaics has declined 8% a year; in California, where 50 MW of solar power were installed in 2005, costs have dropped 5% annually.

Surprisingly, Kenya is the global leader in the number of solar power systems installed per capita (but not the number of watts added). More than 30,000 very small solar panels, each producing only 12 to 30 watts, are sold in that country annually. For an investment of as little as $100 for the panel and wiring, the system can be used to charge a car battery, which can then provide enough power to run a fluorescent lamp or a small black-and-white television for a few hours a day. More Kenyans adopt solar power every year than make connections to the country’s electric grid. The panels typically use solar cells made of amorphous silicon; although these photovoltaics are only half as efficient as crystalline cells, their cost is so much lower (by a factor of at least four) that they are more affordable and useful for the 2 billion people worldwide who currently have no access to electricity. Sales of small solar power systems are booming in other African nations as well, and advances in low-cost photovoltaic manufacturing could accelerate this trend.

Furthermore, photovoltaics are not the only fast-growing form of solar power. Solar-thermal systems, which collect sunlight to generate heat, are also undergoing a resurgence. These systems have long been used to provide hot water for homes or factories, but they can also produce electricity without the need for expensive solar cells. In one design, for example, mirrors focus light on a Stirling engine, a high-efficiency device containing a working fluid that circulates between hot and cold chambers. The fluid expands as the sunlight heats it, pushing a piston that, in turn, drives a turbine.

In the fall of 2005 a Phoenix company called Stirling Energy Systems announced that it was planning to build two large solar-thermal power plants in southern California. The company signed a 20-year power purchase agreement with Southern California Edison, which will buy the electricity from a 500-MW solar plant to be constructed in the Mojave Desert. Stretching across 4,500 acres, the facility will include 20,000 curved dish mirrors, each concentrating light on a Stirling engine about...
the size of an oil barrel. The plant is expected to begin operating in 2009 and could later be expanded to 850 MW. Stirling Energy Systems also signed a 20-year contract with San Diego Gas & Electric to build a 300-MW, 12,000-dish plant in the Imperial Valley. This facility could eventually be upgraded to 900 MW.

The financial details of the two California projects have not been made public, but electricity produced by present solar-thermal technologies costs between five and 13 cents per kilowatt-hour, with dish-mirror systems at the upper end of that range. Because the projects involve highly reliable technologies and mass production, however, the generation expenses are expected to ultimately drop closer to four to six cents per kilowatt-hour – that is, competitive with the current price of coal-fired power.

Blowing in the wind

Wind power has been growing at a pace rivaling that of the solar industry. The worldwide generating capacity of wind turbines has increased more than 25% a year, on average, for the past decade, reaching nearly 60,000 MW in 2005. The growth has been nothing short of explosive in Europe – between 1994 and 2005, the installed wind power capacity in European Union nations jumped from 1,700 to 40,000 MW. Germany alone has more than 18,000 MW of capacity thanks to an aggressive construction program. The northern German state of Schleswig-Holstein currently meets one quarter of its annual electricity demand with more than 2,400 wind turbines, and in certain months wind power provides more than half the state’s electricity. In addition, Spain has 10,000 MW of wind capacity, Denmark has 3,000 MW, and Great Britain, the Netherlands, Italy and Portugal each have more than 1,000 MW.

In the US the wind power industry has accelerated dramatically in the past five years, with total generating capacity leaping 36% to 9,100 MW in 2005. Although wind turbines now produce only 0.5% of the nation’s electricity, the potential for expansion is enormous, especially in the windy Great Plains states. (North Dakota, for example, has greater wind energy resources than Germany, but only 98 MW of generating capacity is installed.

Not smoke, but mirrors

The electricity produced by power-generating stations depends on the phenomenon of an electric current flowing through a wire when it moves in a magnetic field. Power generation, therefore, comes down to getting the wire to move. The most efficient way is to wrap it many times around a shaft that can be turned. That turning can be achieved by using high-pressure steam or water to rotate turbines attached to the shaft, or by heat engines the end-product of which is also shaft rotation.

Those engines use the heat provided them to drive pistons. The heat can come from various sources, including collecting and concentrating the energy of sunlight. The greater the heat, the more efficient the engine.

Considerable interest and ingenuity have been shown in recent decades in designing plant that optimises the concentration of solar energy so as to obtain as much heat as possible from a square metre of solar panel. The most efficient design is a parabolic mirrored dish that concentrates sunlight at a point where its energy heats gas in cylinders, causing pistons in them to move to and fro, thereby rotating their engine’s crankshaft, which in turn rotates the shaft in an electricity generator. The dish is mounted on motorised pedestals that keep it focused on the sun throughout the day. The total installation is known as the solar dish-engine system.

One square metre of mirror produces, weather permitting, one kilowatt of power. The dishes can be constructed to generate 20 kilowatts or more.

Use of the system in coming years could be greatest in the developing world, which generally experiences sun for most of the year and, according to the International Energy Agency, will account for more than half of a doubling of global electricity demand.
there.) If the US constructed enough wind farms to fully tap these resources, the turbines could generate as much as 11 trillion kilowatt-hours of electricity, or nearly three times the total amount produced from all energy sources in the nation last year. The wind industry has developed increasingly large and efficient turbines, each capable of yielding 4 to 6 MW. And in many locations, wind power is the cheapest form of new electricity, with costs ranging from four to seven cents per kilowatt-hour.

The growth of new wind farms in the US has been spurred by a production tax credit that provides a modest subsidy equivalent to 1.9 cents per kilowatt-hour, enabling wind turbines to compete with coal-fired plants. Unfortunately, Congress has repeatedly threatened to eliminate the tax credit. Instead of instituting a long-term subsidy for wind power, the lawmakers have extended the tax credit on a year-to-year basis, and the continual uncertainty has slowed investment in wind farms. Congress is also threatening to derail a proposed 130-turbine farm off the coast of Massachusetts that would provide 468 MW of generating capacity, enough to power most of Cape Cod, Martha's Vineyard and Nantucket.

The reservations about wind power come partly from utility companies that are reluctant to embrace the new technology and partly from so-called 'nimby-ism'. ('Nimby' is an acronym for 'not in my backyard'.) Although local concerns over how wind turbines will affect landscape views may have some merit, they must be balanced against the social costs of the alternatives. Because society’s energy needs are growing relentlessly, rejecting wind farms often means requiring the construction or expansion of fossil-fuel-burning power plants that will have far more devastating environmental effects.

**Green fuels**

Researchers are also pressing ahead with the development of biofuels that could replace at least a portion of the oil currently consumed by motor vehicles. Sugar cane forms the feedstock for this ethanol distillery in the southern Brazilian state of Paraná. Three-quarters of the cars now being produced in Brazil have 'flex-fuel' engines, capable of running on either ethanol or petrol, or any mixture of the two liquids.
vehicles. The most common biofuel by far in the US is ethanol, which is typically made from corn and blended with gasoline. The manufacturers of ethanol benefit from a substantial tax credit: with the help of the $2 billion annual subsidy, they sold more than 16 billion liters of ethanol in 2005 (almost 3% of all automobile fuel by volume), and production is expected to rise 50% by 2007. Some policymakers have questioned the wisdom of the subsidy, pointing to studies showing that it takes more energy to harvest the corn and refine the ethanol than the fuel can deliver to combustion engines. In a recent analysis, though, my colleagues and I discovered that some of these studies did not properly account for the energy content of the by-products manufactured along with the ethanol. When all the inputs and outputs were correctly factored in, we found that ethanol has a positive net energy of almost five megajoules per liter.

We also found, however, that ethanol’s impact on greenhouse gas emissions is more ambiguous. Our best estimates indicate that substituting corn-based ethanol for gasoline reduces greenhouse gas emissions by 18%, but the analysis is hampered by large uncertainties regarding certain agricultural practices, particularly the environmental costs of fertilizers. If we use different assumptions about these practices, the results of switching to ethanol range from a 36% drop in emissions to a 29% increase. Although corn-based ethanol may help the US reduce its reliance on foreign oil, it will probably not do much to slow global warming unless the production of the biofuel becomes cleaner.

But the calculations change substantially when the ethanol is made from cellulosic sources: woody plants such as switchgrass or poplar. Whereas most makers of corn-based ethanol burn fossil fuels to provide the heat for fermentation, the producers of cellulosic ethanol burn lignin – an unfermentable part of the organic material – to heat the plant sugars. Burning lignin does not add any greenhouse gases to the atmosphere, because the emissions are offset by the carbon dioxide absorbed during the growth of the plants used to make the ethanol. As a result, substituting cellulosic ethanol for gasoline can slash greenhouse gas emissions by 90% or more.

Another promising biofuel is so-called green diesel. Researchers have produced this fuel by first gasifying biomass – heating organic materials enough that they release hydrogen and carbon monoxide – and then converting these compounds into long-chain hydrocarbons using the Fischer-Tropsch process. (During World War II, German engineers employed these chemical reactions to make synthetic motor fuels out of coal.) The result would be an economically competitive liquid fuel for motor vehicles that would add virtually no greenhouse gases to the atmosphere. Oil giant Royal Dutch/Shell is currently investigating the technology.

**The need for R&D**

Each of these renewable sources is now at or near a tipping point, the crucial stage when investment and innovation, as well as market access, could enable these attractive but generally marginal providers to become major contributors to regional and global energy supplies. At the same time, aggressive policies designed to open markets for renewables are taking hold at city, state and federal levels around the world. Governments have adopted these policies for a wide variety of reasons: to promote market diversity or energy security, to bolster industries and jobs, and to protect the environment on both the local and global scales. In the US more than 20 states have adopted standards setting a minimum for the fraction of electricity that must be supplied with renewable sources. Germany plans to generate 20% of its electricity from renewables by 2020, and Sweden intends to give up fossil fuels entirely.

Even President George W Bush said, in his now famous State of the Union address in January 2006, that the US is “addicted to oil”. And although Bush did not make the link to global warming, nearly all scientists agree that humanity’s addiction to fossil fuels is disrupting the earth’s climate. The time for action is now, and at last the tools exist to alter energy production and consumption in ways that simultaneously benefit the economy and the environment. Over the past 25 years, however, the public and private funding of research and development (R&D) in the energy sector has withered. Between 1980 and 2005 the fraction of all US R&D spending devoted to energy declined from 10% to 2%. Annual public R&D funding for
The least bad fossil fuel

Although renewable energy sources offer the best way to radically cut greenhouse gas emissions, generating electricity from natural gas instead of coal can significantly reduce the amount of carbon added to the atmosphere. Conventional coal-fired power plants emit 0.25 kilogram of carbon for every kilowatt-hour generated. (More advanced coal-fired plants produce about 20% less carbon.) But natural gas (CH₄) has a higher proportion of hydrogen and a lower proportion of carbon than coal does. A combined-cycle power plant that burns natural gas emits only about 0.1 kilogram of carbon per kilowatt-hour.

Unfortunately, dramatic increases in natural gas use in the US and other countries have driven up the cost of the fuel. For the past decade, natural gas has been the fastest-growing source of fossil-fuel energy, and it now supplies almost 20% of America’s electricity. At the same time, the price of natural gas has risen from an average of $2.50 to $3 per million British thermal units (Btu) in 1997 to more than $7 per million Btu today.

The price increases have been so alarming that in 2003, then Federal Reserve Board Chair Alan Greenspan warned that the US faced a natural-gas crisis. The primary solution proposed by the White House and some in Congress was to increase gas production. The 2005 Energy Policy Act included large subsidies to support gas producers, increase exploration and expand imports of liquefied natural gas (LNG). These measures, however, may not enhance energy security, because most of the imported LNG would come from some of the same OPEC countries that supply petroleum to the US. Furthermore, generating electricity from even the cleanest natural gas power plants would still emit too much carbon to achieve the goal of keeping carbon dioxide in the atmosphere below 450 to 550 parts per million by volume. (Higher levels could have disastrous consequences for the global climate.)

Improving energy efficiency and developing renewable sources can be faster, cheaper and cleaner and provide more security than developing new gas supplies. Electricity from a wind farm costs less than that produced by a natural gas power plant if the comparison factors in the full cost of plant construction and forecasted gas prices. Also, wind farms and solar arrays can be built more rapidly than large-scale natural gas plants. Most critically, diversity of supply is America’s greatest ally in maintaining a competitive and innovative energy sector. Promoting renewable sources makes sense strictly on economic grounds, even before the environmental benefits are considered.◆

energy sank from $8 billion to $3 billion (in 2002 dollars); private R&D plummeted from $4 billion to $1 billion.

To put these declines in perspective, consider that in the early 1980s energy companies were investing more in R&D than were drug companies, whereas today investment by energy firms is an order of magnitude lower. Total private R&D funding for the entire energy sector is less than that of a single large biotech company. (Amgen, for example, had R&D expenses of $2.3 billion in 2005.) And as R&D spending dwindles, so does innovation. For instance, as R&D funding for photovoltaics and wind power has slipped over the past quarter of a century, the number of successful patent applications in these fields has fallen accordingly. The lack of attention to long-term research and planning has significantly weakened our nation’s ability to respond to the challenges of climate change and disruptions in energy supplies.
Calls for major new commitments to energy R&D have become common. A 1997 study by the President’s Committee of Advisors on Science and Technology and a 2004 report by the bipartisan National Commission on Energy Policy both recommended that the federal government double its R&D spending on energy. But would such an expansion be enough? Probably not. Based on assessments of the cost to stabilize the amount of carbon dioxide in the atmosphere and other studies that estimate the success of energy R&D programs and the resulting savings from the technologies that would emerge, my research group has calculated that public funding of $15 billion to $30 billion a year would be required – a fivefold to 10-fold increase over current levels.

Greg F Nemet, a doctoral student in my laboratory, and I found that an increase of this magnitude would be roughly comparable to those that occurred during previous federal R&D initiatives such as the Manhattan Project and the Apollo program, each of which produced demonstrable economic benefits in addition to meeting its objectives. American energy companies could also boost their R&D spending by a factor of 10, and it would still be below the average for US industry overall. Although government funding is essential to supporting early-stage technologies, private-sector R&D is the key to winnowing the best ideas and reducing the barriers to commercialization.

Raising R&D spending, though, is not the only way to make clean energy a national priority. Educators at all grade levels, from kindergarten to college, can stimulate public interest and activism by teaching how energy use and production affect the social and natural environment. Non-profit organizations can establish a series of contests that would reward the first company or private group to achieve a challenging and worthwhile energy goal, such as constructing a building or appliance that can generate its own power or developing a commercial vehicle that can go 200 miles on a single gallon of fuel. The contests could be modeled after the Ashoka awards for pioneers in public policy and the Ansari X Prize for the developers of space vehicles. Scientists and entrepreneurs should also focus on finding clean, affordable ways to meet the energy needs of people in the developing world.

My colleagues and I, for instance, recently detailed the environmental benefits of improving cooking stoves in Africa.

But perhaps the most important step toward creating a sustainable energy economy is to institute market-based schemes to make the prices of carbon fuels reflect their social cost. The use of coal, oil and natural gas imposes a huge collective toll on society, in the form of health care expenditures for ailments caused by air pollution, military spending to secure oil supplies, environmental damage from mining operations, and the potentially devastating economic impacts of global warming. A fee on carbon emissions would provide a simple, logical and transparent method to reward renewable, clean energy sources over those that harm the economy and the environment. The tax revenues could pay for some of the social costs of carbon emissions, and a portion could be designated to compensate low-income families who spend a larger share of their income on energy. Furthermore, the carbon fee could be combined with a cap-and-trade program that would set limits on carbon emissions but also allow the cleanest energy suppliers to sell permits to their dirtier competitors. The federal government has used such programs with great success to curb other pollutants, and several northeastern states are already experimenting with greenhouse gas emissions trading.

Best of all, these steps would give energy companies an enormous financial incentive to advance the development and commercialization of renewable energy sources. In essence, the US has the opportunity to foster an entirely new industry. The threat of climate change can be a rallying cry for a clean-technology revolution that would strengthen the country’s manufacturing base, create thousands of jobs and alleviate our international trade deficits – instead of importing foreign oil, we can export high-efficiency vehicles, appliances, wind turbines and photovoltaics. This transformation can turn the nation’s energy sector into something that was once deemed impossible: a vibrant, environmentally sustainable engine of growth.

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