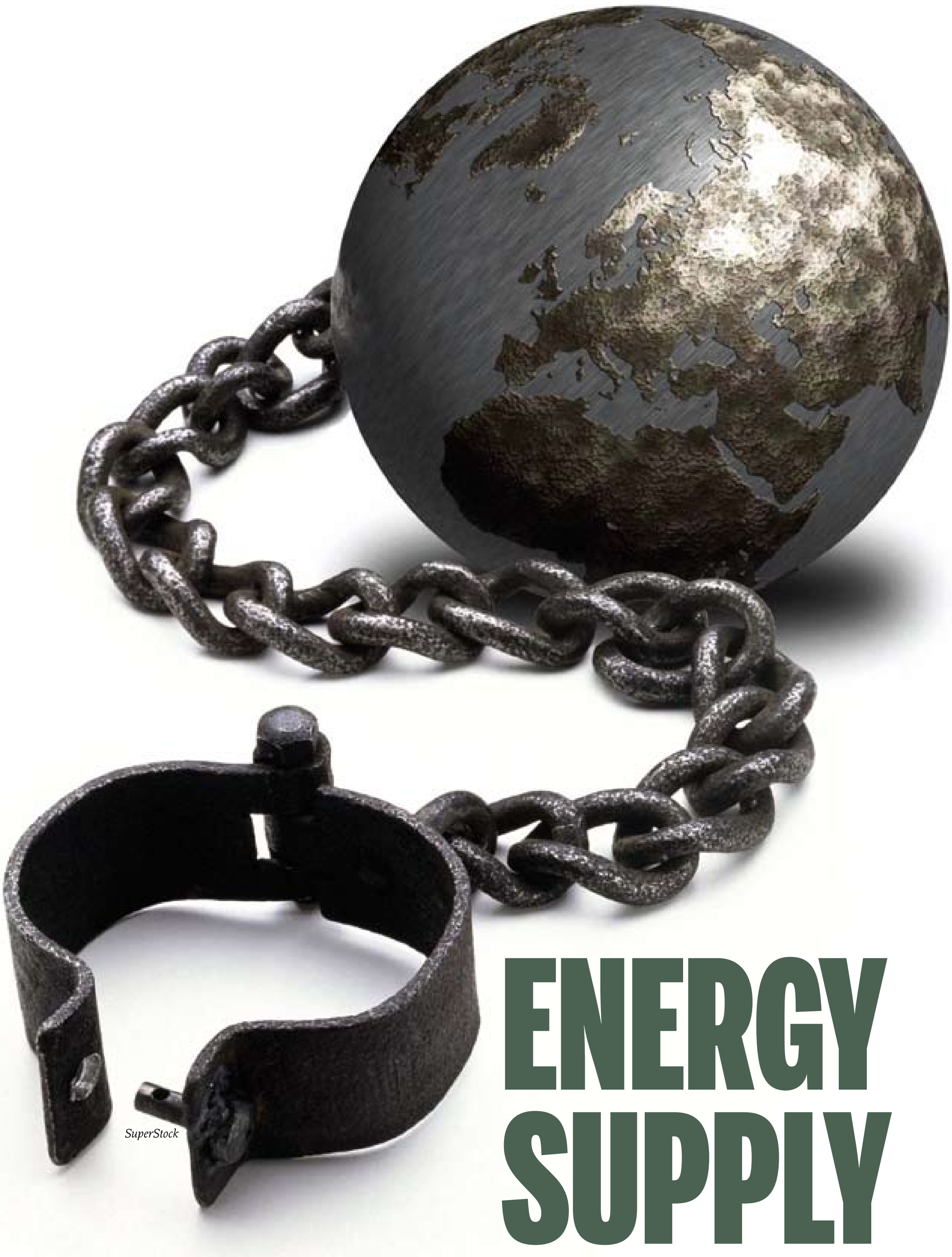

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ENERGY SUPPLY
IN A CARBON-CONSTRAINED WORLD

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.

*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, S*tern 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 Griffiths, 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

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 (CO_2) 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 CO_2 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.

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

Ecoscene/ Michael Gore

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, world-wide 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.

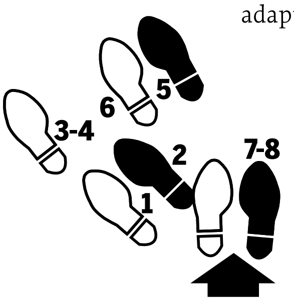
Extreme weather events will probably be of greater significance in swaying public opinion than a gentle warming trend. Although climate science indicates little relationship between global warming and the frequency of hurricanes, there is support for the belief that warming will lead to hurricane intensification.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

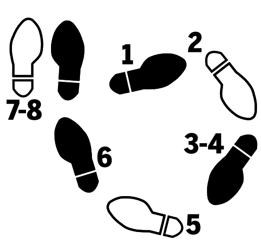
Dirty Dancing

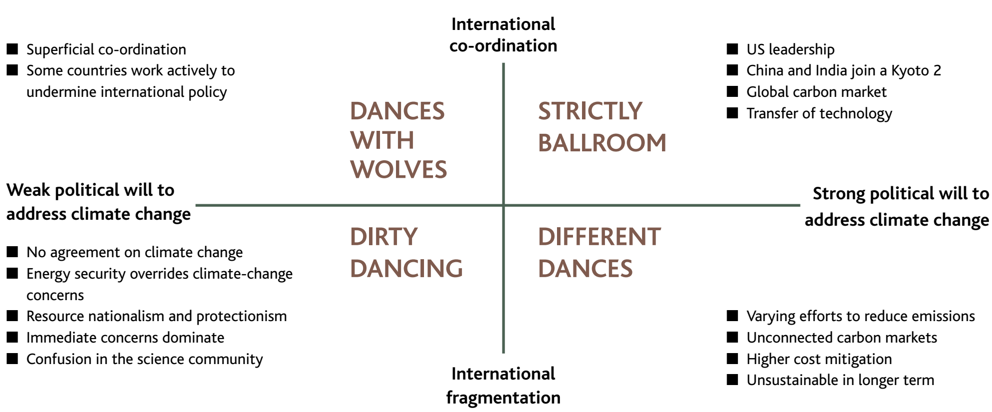
In this scenario there is little or no agreement, especially in the US, that climate change is a priority. As a result, other countries are not prepared to take serious action to reduce emissions, especially where competitiveness might be affected. Uncertainty is likely to be greater in the scientific 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*.[1] 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[2] describe a possible low-carbon future based on technologies that are already largely currently available on a commercial or near-commercial basis.[3] However, the full utilisation of these technologies will require the

Joerg Boethling/ Still Pictures

Solar panels at a solar park in Germany. Already two solar power stations are operational in the country, while others are planned for Portugal, Spain, South Korea, Israel, Australia and California 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.[4] 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.

Fotolia

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.

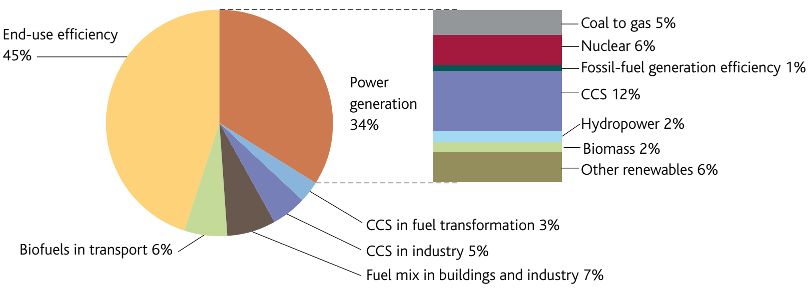
The transport sector is estimated to offer half the potential end-user efficiency gains and these arise principally from continuing incremental improvements in vehicle drive trains and in auxiliary systems such as air conditioners as well as reductions in weight and rolling/air resistance. Many of these 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.

Reduction in CO_2 emissions in the IEA ACT Scenario by technology area

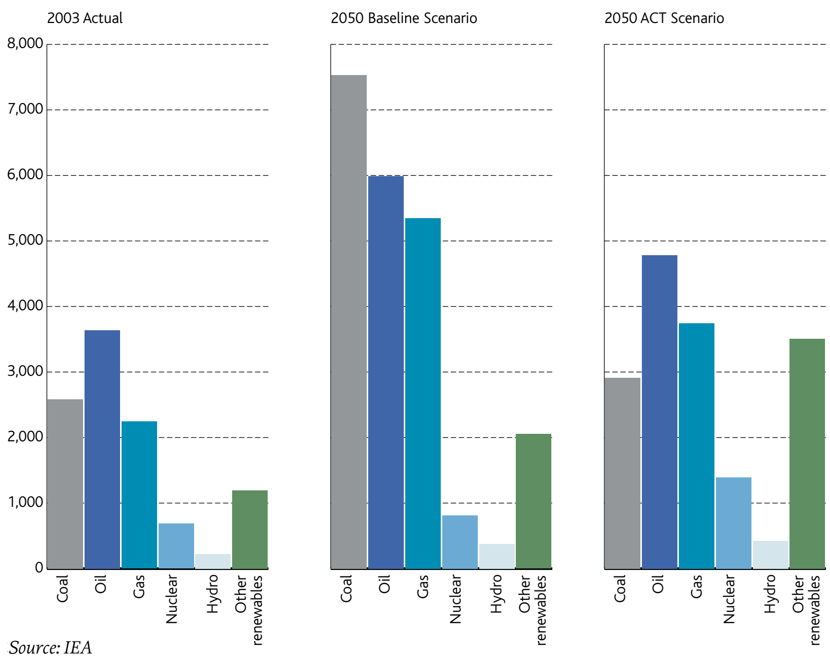
Share of reduction below Baseline Scenario in 2050



Source: IEA

IEA energy supply Scenario projections

Million tonnes oil equivalent



Source: IEA

London Press Service

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. ◆

Carbon capture and storage (CCS)

The second greatest contributor (at about 6.5 Gt CO_2) 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 CO_2 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 CO_2 to the $25/tonne CO_2 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 CO_2 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 CO_2 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.

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

DaimlerChrysler

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[7], 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 CO_2 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 far 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 CO_2 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 CO_2 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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1 International Energy Agency (2006), *Energy Technology Perspectives 2006: Scenarios and Strategies in 2050*, IEA, Paris
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 CO_2 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