SUMMARY AND POLICY IMPLICATIONS

This publication is a response to the Group of Eight (G8) leaders at their Gleneagles Summit in July 2005, and to the International Energy Agency's Energy Ministers who met two months earlier. Both groups called for the IEA to develop and advise on alternative scenarios and strategies aimed at a clean, clever and competitive energy future.

Secure, reliable and affordable energy supplies are fundamental to economic stability and development. The threat of disruptive climate change, the erosion of energy security and the growing energy needs of the developing world all pose major challenges for energy decision makers. They can only be met through innovation, the adoption of new cost-effective technologies, and a better use of existing energy-efficient technologies. *Energy Technology Perspectives* presents the status and prospects for key energy technologies and assesses their potential to make a difference by 2050. It also outlines the barriers to implementing these technologies and the measures that can overcome such barriers.

The Outlook to 2050 and the Role of Energy Technology

The world is not on course for a sustainable energy future. Oil prices at historical highs raise concerns about the long-term balance of supply and demand. CO_2 emissions have increased by more than 20% over the last decade. Indeed, if the future is in line with present trends as illustrated by the *World Energy Outlook 2005* Reference Scenario, CO_2 emissions and oil demand will continue to grow rapidly over the next 25 years. This is after taking account of energy efficiency gains and technological progress that can be expected under existing policies. Extending this outlook beyond 2030 shows that these worrisome trends are likely to get worse. In the Baseline Scenario prepared for this study, CO_2 emissions will be almost two and a half times the current level by 2050. Surging transport demand will continue to put pressure on oil supply. The carbon intensity of the world's economy will increase due to greater reliance on coal for power generation – especially in rapidly expanding developing countries with domestic coal resources – and the increased use of coal in the production of liquid transport fuels.

But this alarming outlook can be changed. The Accelerated Technology scenarios (ACTs) – that form the backbone of this book – demonstrate that by employing technologies that already exist or are under development, the world could be brought onto a much more sustainable energy path. The scenarios show how energy-related CO_2 emissions can be returned to their current levels by 2050 and how the growth of oil demand can be moderated. They also show that by 2050, energy efficiency measures can reduce electricity demand by a third below the Baseline levels. Savings from liquid fuels would equal more than half of today's global oil consumption, offsetting about 56% of the growth in oil demand foreseen in the Baseline scenario.

The substantial changes demonstrated in the ACT scenarios are grounded in:

- Strong energy efficiency gains in the transport, industry and buildings sectors.
- Electricity supply becoming significantly decarbonised as the power-generation mix shifts towards nuclear power, renewables, natural gas and coal with CO_2 capture and storage (CCS).
- Increased use of biofuels for road transport.

Nevertheless, even in the ACT scenarios, fossil fuels still supply most of the world's energy in 2050. Demand for oil, coal (except in one scenario) and natural gas are all greater in 2050 than they are today. Investment in conventional energy sources will, therefore, remain essential.

In all five of the ACT scenarios, demand for energy services is assumed to grow rapidly, especially in developing countries. The scenarios do not imply that the growth in demand for energy services is constrained in developing or developed countries. Rather they show how this demand can be met more intelligently and with lower CO_2 emissions through the implementation of a wide range of policies including increased research, development and demonstration (RD&D) efforts and deployment programmes, as well as economic incentives to advance the uptake of low-carbon technologies. The policies considered are the same across all five ACT scenarios. What varies are assumptions about how quickly energy efficiency gains can be achieved, about how quickly the cost of major technologies such as CCS, renewables and nuclear can be reduced, and about how soon these technologies can be made widely available. A sixth scenario, TECH Plus, illustrates the implications of making more optimistic assumptions on the rate of progress for renewables and nuclear electricity generation technologies, as well as for advanced biofuels and hydrogen fuel cells in the transport sector.

The costs of achieving a more sustainable energy future in the ACT scenarios are not disproportionate, but they will require substantial effort and investment by both the public and private sectors. None of the technologies required are expected – when fully commercialised – to have an incremental cost of more than USD 25 per tonne of avoided CO_2 emissions in all countries, including developing countries. For comparison, this cost is less than the average price for CO_2 permits under the European trading scheme over the first four months of 2006. A price of USD 25 per tonne of CO_2 would add about USD 0.02 per kWh to the cost of coal-fired electricity and about USD 0.07/litre (USD 0.28/gallon) to the cost of gasoline. The *average* cost per tonne CO_2 emissions reduction for the whole technology portfolio, once all technologies are fully commercialised, is less than USD 25. However, there will be significant additional transitional costs related to RD&D and deployment programmes to commercialise many of the technologies over the next couple of decades. The import price of oil will be lower, as reduced demand will put less pressure on more expensive supply options. This cost reduction may not be apparent to consumers, however, since most of it will be balanced by the increased cost of promoting low-carbon technologies.

There are large uncertainties when looking 50 years ahead. The ACT scenarios illustrate a range of possible outcomes based on assumptions that are more, or less, optimistic with regard to cost reductions achieved by technologies such as renewables, nuclear and CCS in power generation. Yet, despite all the uncertainties, **two main conclusions** from the analysis seem robust. First, technologies do exist that can make a difference over the next 10 to 50 years. Second, none of these technologies can make a sufficient difference on their own. Pursuing a portfolio of technologies will greatly reduce the risk and potentially the costs, if one or more technologies fail to make the expected progress.

The following discussion summarises the key technologies identified by the ACT scenarios that help build a portfolio for a sustainable energy future.

Energy Efficiency in Buildings, Industry and Transport

Accelerating progress in energy efficiency is indispensable. The recent slowdown in energy savings in OECD countries must be reversed. This is indeed possible; there is still significant scope for adopting more efficient technologies in buildings, industry and transport. In non-OECD countries, the potential for improvement is even greater, as rapidly expanding economies offer enormous opportunities for investment in energy-efficient technologies.

In many countries, new **buildings** could be made 70% more efficient than existing buildings. Some of the exciting new technologies that can contribute to this transformation have not yet been commercialised, but most have. Windows are now available with three times the insulation value of their predecessors. Modern gas and oil furnaces have attained 95% efficiency. Efficient air conditioners use 30 to 40% less energy than the models of ten years ago. District heating, heat pumps and solar energy can all save energy. Improved lighting could yield cost-effective savings of 30 to 60%. Major improvements have been made in refrigerators, water heaters, washing machines and dishwashers. Stand-by power (leaking electricity) absorbs about 10% of residential electricity in IEA countries, but technologies exist that can substantially reduce this consumption. New technologies such as "smart" metering, micro combined-heat-and-power generation, fuel cells and solar photovoltaics are opening up new ways to provide energy services.

In **industry** there is huge potential to reduce energy demand and CO_2 emissions through improved efficiency of motors, pumps, boilers and heating systems; increased energy recovery in materials-production processes; increased recycling of used materials; adoption of new and more advanced processes and materials; and a higher efficiency of materials use. The biggest sources of industrial CO_2 emissions are the iron and steel industry (26%), the production of other minerals such as cement, glass, and ceramics (25%), and chemicals and petrochemicals (18%). New cutting-edge industrial technologies with substantial potential to save energy and CO_2 emissions include: advanced membranes that can replace distillation in some petrochemical processes; "direct casting" in iron and steel; and the use of bio-feedstocks in the petrochemical industry to replace oil and natural gas.

Improving energy efficiency in the **transport** sector is of special importance, since this sector consumes the bulk of oil products and has the fastest growing emission profile. The efficiency of conventional gasoline and diesel vehicles can be substantially improved. Promising technologies include hybrid vehicles and advanced diesel engines. Turbochargers, fuel injection and advanced electronic methods of engine control can help cut fuel consumption. New materials and more compact engines lead to lighter and more fuel-efficient vehicles. Large efficiency gains are also possible in vehicle appliances, especially air conditioning. Some practical measures, such as ensuring that tyres are correctly inflated, can make a surprisingly significant difference.

Energy efficiency gains are a first priority for a more sustainable energy future. In the ACT scenarios, improved energy efficiency in the buildings, industry and transport sectors leads to between 17 and 33% lower energy use than in the Baseline scenario by 2050. Energy efficiency accounts for between 45% and 53% of the total CO_2 emission reduction relative to the Baseline in 2050, depending on the scenario. In a scenario in which global efficiency gains relative to the Baseline are only 20% by 2050, global CO_2 emissions increase by more than 20% compared to the other ACT scenarios.

Clean Coal and CO_2 Capture and Storage Technologies

CO_2 capture and storage technologies (CCS) can significantly reduce CO_2 emissions from power generation, industry and the production of synthetic transport fuels. CCS could reduce CO_2 emissions from coal and natural gas use in these sectors to near zero. The cost of CCS is high, but it could fall below USD 25 per tonne of CO_2 by 2030. When the captured CO_2 can be used for enhanced oil recovery (EOR), costs could be lower and even negative in some cases. However, the global long-term potential for CO_2 EOR is small relative to global emissions from the power generation sector.

All the individual elements needed for CCS have been demonstrated, but there is an urgent need for an integrated full-scale demonstration plant. Particularly when used with coal, it is important that coal plants are highly efficient in order to limit the cost increase of using CCS. More efficient technologies for coal combustion are already available or in an advanced stage of development. These include high-temperature pulverised coal plants and integrated coal-gasification combined-cycle (IGCC).

In the ACT scenarios, CCS technologies contribute between 20% and 28% of total CO_2 emission reductions below the Baseline Scenario by 2050. Clean coal technologies with CCS offer a particularly important opportunity to constrain emissions in rapidly growing economies with large coal reserves, such as China and India. CCS is indispensable for the role that coal can play in providing low-cost electricity in a CO_2 constrained world. This is illustrated in a scenario where CCS is *not* included as an option. In this scenario, global coal demand is almost 30% lower than in the scenarios that include CCS and CO_2 emissions are between 10% and 14% higher.

Electricity Generation from Natural Gas

The share of natural gas in electricity generation remains relatively robust in all of the ACT scenarios, ranging from 23 to 28% of total generation in 2050. This represents a more than a doubling of gas-based electricity generation from 2003 levels. Ample reserves of gas exist to meet demand, but many factors will affect its actual availability and price. Natural gas emits only about half as much CO_2 as coal per kWh. The improved efficiency of gas-fired electricity generating plants is one of the success stories of modern power generation technologies. The latest combined-cycle gas plants reach efficiencies of around 60%. More widespread use of this technology can reduce emissions significantly. To achieve even higher efficiencies, new materials will be needed that can withstand very high temperatures.

Electricity Generation from Nuclear Power

Nuclear energy is an emission-free technology that has progressed through several "generations". "Generation III" was developed in the 1990s, with a number of advances in safety and economics, including "passive safety" features. Eleven countries, including those OECD countries with the largest nuclear power sectors, have joined together to develop "Generation IV" nuclear power plants. Three key issues present major obstacles to nuclear energy's further exploitation: their large capital cost; public opposition due to the perceived threats of radioactive waste and nuclear accidents; and the possible proliferation of nuclear weapons. The development of Generation IV reactors aims to address these issues.

Assuming that these concerns are met, increased use of nuclear power can provide substantial CO_2 emission reductions. In the ACT scenarios, nuclear accounts for 16 to 19% of global electricity generation in 2050. The increased use of nuclear power relative to the Baseline Scenario accounts for 6 to 10% of the emissions reduction in 2050. In a scenario with more pessimistic prospects for nuclear, its share of electricity generation drops to 6.7%, the same level as in the Baseline. In the more optimistic TECH Plus scenario, nuclear power accounts for 22.2% of electricity generation in 2050.

Electricity Generation from Renewables

By 2050, the increased use of renewables such as hydropower, wind, solar and biomass in power generation contributes between 9% and 16% of the CO_2 emission reductions in the ACT scenarios. The share of renewables in the generation mix increases from 18% today, to as high as 34% by 2050. In a scenario with less optimistic assumptions about cost reductions for renewable technologies, their share of generation is 23% in 2050. On the other hand, in the TECH Plus scenario, which is more optimistic for both renewable and nuclear technologies, the share of renewables reaches more than 35% by 2050.

Hydropower is already widely deployed and is, in many areas, the cheapest source of power. There is considerable potential for expansion, particularly for small hydro plants. Hydropower remains the largest source of renewable generation in all the ACT scenarios.

The costs of **onshore and offshore wind** have declined sharply in recent years through mass deployment, the use of larger blades and more sophisticated controls. Costs depend on location. The best onshore sites, which can produce power for about USD 0.04 per kWh, are already competitive with other power sources. Offshore installations are more costly, especially in deep water, but are expected to be commercial after 2030. In situations where wind will have a very high share of generation, it will need to be complemented by sophisticated networks, back-up systems, or storage, to accommodate its intermittency. In the ACT scenarios, power generation from wind turbines is set to increase rapidly. In most of the scenarios, wind is second to hydropower as the most important renewable source.

The combustion of **biomass** for power generation is a well-proven technology. It is commercially attractive where quality fuel is available and affordable. Co-firing a coal-fired power plant with a small proportion of biomass requires no major plant modifications, can be highly economic and can also contribute to CO_2 emission reductions.

The costs of high-temperature **geothermal** resources for power generation have dropped substantially since the 1970s. Geothermal's potential is enormous, but it is a site-specific resource that can only be accessed in certain parts of the world for power generation. Lower-temperature geothermal resources for direct uses like district heating and ground-source heat pumps are more widespread. RD&D can further reduce the costs and increase the scope of geothermal power.

Solar **photovoltaic (PV)** technology is playing a rapidly growing role in niche applications. Costs have dropped with increased deployment and continuing R&D. Concentrating solar power (CSP) also has promising prospects. By 2050, however, solar's (PV and CSP) share in global power generation will still be below 2% in all the ACT scenarios.

Biofuels and Hydrogen Fuel Cells in Road Transport

Finding carbon-free alternatives in the transport sector has proven to be a greater challenge than in power generation. Ethanol derived from plant material is an attractive fuel with good combustion qualities. It has most commonly been blended with gasoline (10% ethanol and 90% gasoline), but Brazil has successfully introduced much higher blends with only minor vehicle modifications. Ethanol from sugar cane is produced in large volumes in Brazil, and it is fully competitive with gasoline at current oil prices. Today's ethanol production uses predominately starch or sugar crops, limiting the available feedstock, but new technology could enable lignocellulosic biomass feedstocks to be used as well. This is currently one of the cutting edge areas of energy technology research.

The use of hydrogen from low-carbon or zero-carbon sources in fuel-cell vehicles could practically decarbonise transport in the long run. But a switch to hydrogen will require huge infrastructure investments. In addition, although recent advances in hydrogen fuel-cell technologies have been impressive, they are still very expensive.

The increased use of biofuels in transport accounts for around 6% of the CO_2 emission reductions in all the ACT scenarios, while the contribution from hydrogen is very modest. In the TECH Plus scenario, however, hydrogen consumption grows to more than 300 Mtoe per year in 2050 and accounts for around 800 Mt of CO_2 savings, while the fuel-efficiency impact of fuel cells adds another 700 Mt CO_2 of savings. Hydrogen and biofuels provide 35% of total final transport energy demand in 2050 in the TECH Plus scenario, up from around 13% in the ACT scenarios and 3% in the Baseline scenario. This returns primary oil demand in 2050 back to about today's level.

Beyond 2050

Bringing CO_2 emission levels in 2050 back to current levels, as illustrated by the ACT scenarios, could offer a pathway to eventually stabilise CO_2 concentrations in the atmosphere. But for this to happen, the trend of declining CO_2 emissions achieved by 2050 would have to continue into the second half of the 21st century. In approximate terms, the ACT scenarios show how electricity generation can be significantly decarbonised by 2050. Decarbonising transport, a more difficult task, would need to be accomplished in the following decades.

The more ambitious technology assumptions of the TECH Plus scenario, result in CO_2 emissions being reduced by 16% below current levels by 2050. This outcome could be achievable, but it would be risky to rely on the even faster rate of technical progress assumed in this scenario. The TECH Plus scenario could also be regarded as providing an idea of the trends that may be developed more strongly, and perhaps with more certainty, in the second half of the century.

Implementing the ACT Scenarios: Policy Implications

It will take a huge and co-ordinated international effort to achieve the results implied by the ACT scenarios. Public and private support will be essential. Unprecedented co-operation will be needed between the developed and developing nations, and between industry and government. The task is urgent. It must be carried out before a new generation of inefficient and high-carbon energy infrastructure is locked into place. The effort will take decades to complete and it will require significant investments. Yet, the benefits will be substantial, and not only for the environment. Lower energy consumption, together with reduced air pollution and CO_2 emissions could help lift possible constraints that concerns about energy supply and environmental degradation may otherwise impose on economic growth.

Implementing the ACT scenarios will require a transformation in the way power is generated; in the way homes, offices and factories are built and used; and in the technologies used for transport. In the end, it is the private sector that will have to deliver the changes required. But the market on its own will not always achieve the desired results. Governments have a major role to play in supporting innovative R&D and in helping new technologies to surmount some daunting barriers. Government, industry and consumers will have to work hard together.

Energy Efficiency Is Top Priority

Improving energy efficiency is often the cheapest, fastest and most environmentally friendly way to meet the world's energy needs. Improved energy efficiency also reduces the need for investing in energy supply. Many energy efficiency measures are already economic and they will pay for themselves over their lifetime through reduced energy costs. But there are still major barriers to overcome. Consumers are often ill-informed. Few are concerned with energy efficiency when buying appliances, homes or cars. Even business management tends to give energy efficiency a low priority in decision making. There are also opportunities for energy efficiency that consumers never see because the manufacturers of refrigerators, televisions or cars do not always take full advantage of the technologies that exist to make their products more energy efficient. A wide range of policy instruments are available, including public information campaigns, non-binding guidelines, labels and targets, public-sector leadership in procurement, binding regulations, standards, and fiscal and other financial incentives.

Governments should work to help industry and consumers to adopt and demand advanced technologies that will deliver the same or better services at lower costs.

Well-focused R&D Programmes Are Essential

There is an acute need to stabilise declining budgets for energy-related R&D and then increase them. More R&D in the private sector is critical. Some forward-looking companies are increasing their commitments, but this trend needs to continue and broaden. For technologies that are already commercial, the private sector is best placed to tailor ongoing research and development to the market's needs.

Nevertheless, government–funded R&D will remain essential, especially for promising technologies that are not yet commercial. Government R&D budgets in IEA countries are well below the levels that they reached in response to the oil price shocks of the 1970s and have been static or in decline over the past decade. Budgets for energy R&D and deployment programmes need to be reviewed if the results of the ACT scenarios are to be realised. Some of the areas with the greatest potential include advanced bio-fuels, hydrogen and fuel cells, energy storage and advanced renewables. There are also some interesting areas of basic science – especially bio-technologies, nano-technologies and materials – which could have far-reaching implications for energy in the long term.

The Transition from R&D to Technology Deployment Is Critical

The deployment phase can require considerably more resources than the R&D phase. Several new technologies that are already on the market need government backing if they are to be mass deployed. Many renewable energy technologies are in this position. The "valley of death" that new technologies face on the way to full commercialisation must be bridged. Experience shows that new technologies benefit from cost reductions through "technology learning" as deployment increases. Governmental deployment programmes can also activate R&D by private industry by creating expectations of future markets for the new technology.

There is a particularly urgent need to commercialise advanced coal-fired power plants with CO_2 capture and storage. If this is done, coal can continue to play a major role in the energy mix to 2050, significantly reducing the costs of shifting to a more sustainable energy future. To accelerate the introduction of CCS, at least 10 full-scale integrated coal-fired power plants with CCS are needed by 2015 for demonstration. These plants will cost between USD 500 million and USD 1 billion each. The projects can only be accomplished if governments strengthen their commitment to CCS development and deployment and work closely with the private sector. Involvement of developing countries with large coal reserves, such as China, will be crucial in this process. Similar initiatives will be needed to commercialise Generation IV nuclear technology.

Governments Need to Create a Stable Policy Environment that Promotes Low-carbon Energy Options

New energy technologies may be more expensive, even after full commercialisation, than those they are designed to replace. For example, CCS technologies will not make a significant impact unless lasting economic incentives to reduce CO_2

emissions are put in place. The ACT scenarios include widespread implementation of technologies with an incremental cost of up to USD 25 per tonne of CO_2 in 2050. This could be achieved in many ways, such as national or international cap-and-trade schemes, but also through national fiscal or regulatory action. Incentives are needed in developed as well as in developing countries. Incentives for energy-intensive industries will have to be internationally co-ordinated to avoid the risk that factories might relocate to lightly regulated regimes, thereby actually increasing global CO_2 emissions.

Non-economic Barriers Must also Receive Attention

There are a range of other barriers that are not economic or technical that can delay or prevent innovation and market deployment of new energy technologies. These barriers can take many forms, including planning and licensing rules, lack of information and education, health and safety regulations, and lack of co-ordination across different sectors. All these need attention if the potential of promising technologies is to be realised.

Collaboration between Developed and Developing Countries Will be Needed

By 2050, most of the world's energy will be consumed in developing countries, many of which are experiencing rapid growth in all energy consuming sectors. Developing countries will therefore also need to consider energy security and CO_2 abatement policies. A significant transformation of the global energy economy is required to meet the legitimate aspirations of developing countries' citizens for energy services, to secure supplies and to ensure sustainability. Developed countries have an important role to play in helping developing economies to leapfrog the technology development process and to employ efficient equipment and practices through technology transfer, capacity building and collaborative RD&D efforts. Fast-growing developing countries offer opportunities to accelerate technology learning and bring down the costs of technologies, such as energy-efficient equipment.