TECHNOLOGY FUTURES

Shell
GameChanger

Technology Futures

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Foreword

In 2004, Shell GameChanger embarked on a journey to identify technology pathways to the future. History has shown that not everything that is possible will achieve mass-market impact. Society may reject new technology that it mistrusts or thinks unacceptable for a range of different reasons, ranging from cost to moral values – hydrogen fuel cells, genetically manipulated crops and stem cell research are examples of that. So, to try to understand how a range of technologies might emerge over time, we looked at the social forces driving change – many of them highlighted in Shell's Global Scenarios. These insights were captured in a book called Technology Futures 2004 published by GameChanger.

Many of the issues we addressed at that time have since become increasingly relevant and visible to society: the global demand for energy continues to grow; the supply of 'easy oil' will struggle to keep up with this accelerating demand and the growing use of coal – the most convenient alternative for oil and gas but also the dirtiest hydrocarbon energy source – will increase greenhouse gas emissions. The problem is not that the world is running out of oil; according to the International Energy Agency there could be roughly 20 trillion barrels oil equivalent of oil and natural gas in place – enough for 400 years at the current rate of consumption. But not all of this is recoverable with existing technology. The challenge for the future will be finding new ways to access and convert these resources into affordable energy in socially and environmentally responsible ways.

Looking back on the Technology Futures 2004 material we have been amazed at the speed of development of many of the pathways. Events that we thought would take a decade have already happened and the rate of convergence of pathways and technologies continues to increase. Issues such as energy security and particularly climate change have become hot topics in the media. Society, governments and city mayors are forming strong views and policies in response.

Against this backdrop, in 2007, GameChanger set out to explore the latest developments in the world of science and innovation. The initiative focused on three broad themes: the range of energy resources available to meet growing demand; the processes for converting these resources into usable forms of energy; and the end uses of energy.

Instead of reviewing the technologies that Shell is more familiar with, we put the spotlight on technologies being developed in other sectors that could have a significant impact on the energy system (e.g. nanotechnology, information technology and biotechnology).

As the basis of our research we interviewed some 40 technology thought-leaders from different industries, academia, journalism and business, and reviewed the latest scientific literature. Two workshops brought these people together to share insights and views, and collectively make sense of the technological possibilities for addressing the energy challenge. The project then explored the forces – and tensions between those forces – that drive companies, governments and societies to make choices that will help turn these technological possibilities into probabilities.

As in 2004, one workshop took place in the U.K. The second took place this time in Bangalore, India, and was attended by some of the most important thought-leaders from the region – well known as a powerhouse of innovation and technology in recent decades. The focus of the events was the future of energy – not the future of Shell.

The purpose was to think critically and realistically about the technology drivers and obstacles that may play a role in addressing the big energy-related issues facing society.
Again we have captured the highlights of the discussions in the form of a book - Technology Futures.

The book does not set out to predict the future but tries to provide insight into the differing opinions and perspectives, the conversations and collective sense-making that occurred during the workshops, and the technologies discussed.

The Technology Futures initiative helps Shell to bring the knowledge and views of external participants in the energy system into our organisation, to stimulate and focus research and innovation and also to inform decisions that our company is taking today that will contribute towards determining the future shape of the energy system. The content of this book reflects the collective views expressed during the workshops. These views are not necessarily shared by Shell and should not be seen as predictions regarding the future. The material has, however, challenged our thinking and improved our understanding of the world to come. I hope you, the reader, will also find this to be the case. ■

Leo Roodhart & Dave McCormick
Shell GameChanger

Introduction to Technology Futures

What charities fear most is compassion fatigue. There is so much wrong with the world, and so many good causes trying to put things right, that people no longer feel able to choose between them - and may just give up on them all.

Today, we are being hit from all sides by so many conflicting and contradictory opinions about energy and the environment that the easy escape is to assume that someone somewhere knows best and has the situation under long-term control.

So why not book another flight, run another deep bath and leave the stair lights on all night? After all, the cost of wasting energy and water has, until recently, been low enough for many people to ignore. And the extent of any damage done to the environment has been open to debate and likely to affect only remote places that we see on the news.

Over the last five years, though, the rules of engagement have changed radically. The prices of oil and gas have risen fast enough to hurt when we fill up at the pump, or pay home heating bills. Water metering makes us pay for what we waste. Hosepipe bans remind us that even wet countries can run short of clean water.

As happened twenty years ago when scientists established the causal link between smoking and cancer, the connection between releasing carbon dioxide into the atmosphere by burning fossil fuels and global warming is becoming increasingly hard to ignore.

Students with ecological ideals and fresh ideas have married, bought homes, had children and become decision-making managers or opinion-forming media pundits. Others have taken up careers in education. The children they teach now challenge their parents' behaviour. Freak weather storms and floods that wreck homes

– sometimes without valid insurance cover – reinforce the message that the Earth may not be immune to humans' behaviour.

Politicians and business are taking climate change more seriously now as well. Losing the US presidential election gave Al Gore the time and freedom to crusade with a presentation that was turned into the film. An Inconvenient Truth. Every politician now feels the need for an environmental message to pledge. Anyone without a "green" policy is effectively unelectable. Big companies have mission statements on sustainability and clean credentials.

Yet, the comforting feeling that someone somewhere has everything under control has been undermined by a loss of trust in politicians and corporate scandals such as Enron. Thinking people are now hungry for facts they can trust and for balanced information they can rely on. But peer-reviewed books are out of date before they are published. The Internet provides the best source of up-to-date information but is reliable only in parts, with no reliable guide to which parts can be relied on.

Urban myths are usually easy to spot for what they are. But how do we know when scientific information has been softened at the edges because the researcher has been sponsored by a commercial venture with shareholders' interests as first priority? Governments fund think tanks, which talk behind closed doors. Companies hire consultants to help them understand the future. But the results are usually confidential and commercially sensitive. Published reports are heavily edited.

This is where the Technology Futures programme comes in. It provides an impartial view of the collective insights of a wide-ranging group of experts. The Technology Futures programme is part of GameChanger – a strategic innovation group inside Shell.

The idea behind the programme is simple: gather several dozen experts from different disciplines, directly or indirectly related to energy; host them in a closed environment for several days, while continually changing the mix of small discussion groups. Feed them with topics chosen to trigger debate, all the while making written notes under the Chatham House promise of complete anonymity on everything said. Innovaro – an independent company specialising in strategic innovation – choreographed these meetings.

As with the first Futures report, published in 2004, this report looks at what new technologies might be possible twenty years from now. The biggest and most obvious difference between the two events was the emergence of climate change as a prime topic. Hardly mentioned in 2004, it became a recurrent theme in 2007 – still dismissed by some participants, but taken seriously by most.

A clear underlying message emerged: too many people now expect unlimited and low-cost access to limited natural resources. Our experts agreed that this is not sustainable. There is no magic wand to make the growing problems go away. For every hopeful scenario there will be constraints, often unforeseen and ranging from "Not in My Back Yard" objections to disaster on the scale of Chernobyl.

There were two GameChanger sessions held in contrasting locations, one close to London and the other in Bangalore, India – a country where three hundred million people live on a dollar a day and a city which is experiencing first hand both the benefits and the trauma of moving from an agricultural to a high-tech economy. The roads in Bangalore are now so clogged with two, three and four-wheeled motor transport that crossing a street on foot is a life-threatening experience and the air is choked with exhaust fumes.

There are few places where technology has a greater potential to change the way people live, and it's happening already. Amongst the traffic, cows forage for refuse then lie by the roadside to chew the cud. Yet advertisements on the same roadside offer classes teaching the kind of English needed to answer phones in call centres outsourced from the west. Education is seen as the way to escape poverty and children beg for pens to write with, rather than pennies. Broadband access in Bangalore was far more reliable than in England. Outside the city, largely unmade tracks serve as main roads, except where Western companies have invested in a good road to their own front door.

Such obvious paradoxes helped fuel the debates between experts from a wide range of companies and trade bodies from around the world. They included:

The author of a book on future technology;
An information technologist from New Zealand;
Scientists from Singapore;
A truck manufacturer;
A government defence specialist;
Several IT specialists;
An architect;
An intellectual property rights lawyer;
Leading authorities in nano technology and superconductivity;
A pioneer in electric cars;
An entrepreneur;
A mobile phone designer;
An aircraft manufacturer;
Coal and oil industry engineers, scientists and policy makers; and
University and college lecturers from half a dozen countries.

This report comprises the following sections:

- **An introduction to the energy system**: a primer on today's energy system that examines current production sources.
- **New production sources**: an exploration of possible new supplies of energy. This section takes a closer look at the potential of biomass conversion, nuclear, solar, wind and wave technologies.
- **Technologies that enable an electric world**: an analysis of the increasing importance of electricity. This section highlights two important factors in the use of electricity: storage and superconductivity.
- **Technologies that change the game**: a look at the convergence of various technologies that could have a profound impact across the energy system.
- **Impacts and implications**: finally an examination of how expected changes in technology will affect society and the energy system.

Each section includes explanations of the technologies themselves and a summary of the expert conversations setting out some of their enablers and constraints, supported by relevant facts and figures. What follows can be thought of as an opportunity to eavesdrop on what was said. ■

Introduction: The Energy System

The world's energy system is currently dominated by fossil fuels. Modern society as we know it cannot function without electricity from power stations or liquid fuels, all of which are derived from coal, gas and oil – hugely concentrated sources of energy.

In the home, lights rely on electricity. Central heating boilers work with gas. So do kitchen ovens. A wood-burning stove can do a good job of heating and cooking but it can't power the lights or TV.

We are, in short, dependent on fossil fuels at the moment. If power stations tried to replace coal, gas or oil with fresh firewood as their energy source, the amount of power generated would be drastically reduced. There would be brownouts (partial blackouts) and power cuts, and the economy would grind to a halt.

Trains run on electricity, either generated on board by burning diesel oil, or through wires or rails connected to the grid. There is no going back to the age of steam and the appalling smoke pollution caused by shovelling logs or coal into a fiery furnace.

Cars burn fuel to create mechanical energy, or rely on stored electricity that has been generated by burning fossil fuel. "Burning firewood to commute is not an alternative option."

"Wood burning aircraft just won't fly."

Fossil fuels are just old biomass. Plant and animals grew, died, decayed and compacted over millenia to form hugely concentrated energy sources such as coal, oil and gas. Burning these concentrated resources releases a lot of very useful heat but also releases greenhouse gases like carbon dioxide that were previously locked away.

The natural concentration process that creates fossil fuel takes a very long time - millions of years. That's precisely why reserves are running out, and getting harder to find. The trick is to find new ways of extending the life of fossil fuel or to develop enough alternative energy sources that can compete with fossil fuels and meet the future scale of demand. The challenge is for these alternatives to achieve mass-market impact quickly enough to satisfy rapidly growing demand.

This Technology Futures report focuses on emerging technologies outside the fossil-fuel industry, and so does not discuss in detail those technologies that aim to secure more oil, gas or coal-based energy.

The Current Energy System

Energy is the ability to do work. The energy industry is concerned not with the *creation* of energy resources but rather the *conversion* of primary energy sources like crude oil and sunlight into a form that consumers can more readily use – such as liquid hydrocarbons and electricity – for a range of needs such as transport or providing heat and light for homes. Converting primary energy into usable forms is a process that requires energy itself and is often inefficient: as energy is converted, some is lost as heat, for example.

The energy system refers to the complex interaction of all potential sources of energy, conversion technologies, distribution routes and end-use activities.

The global energy system currently relies mainly on hydrocarbons such as oil, gas and coal, which together provide nearly 80 per cent of energy resources. Traditional biomass – such as wood and dung – accounts for 11 per cent and nuclear for 6 per cent, whilst all renewable sources combined contribute just 3 per cent.

Energy resources, with the exception of nuclear, are ultimately derived from the sun. Non-renewable resources such as coal, oil and gas are the result of a process that takes millions of years to convert sunlight into hydrocarbons. Renewable energy sources – such as biomass, wind, wave, tidal, sea currents, hydro-electricity, solar energy and geothermal – convert solar radiation, the rotation of the earth and geothermal energy into usable energy in a far shorter time.

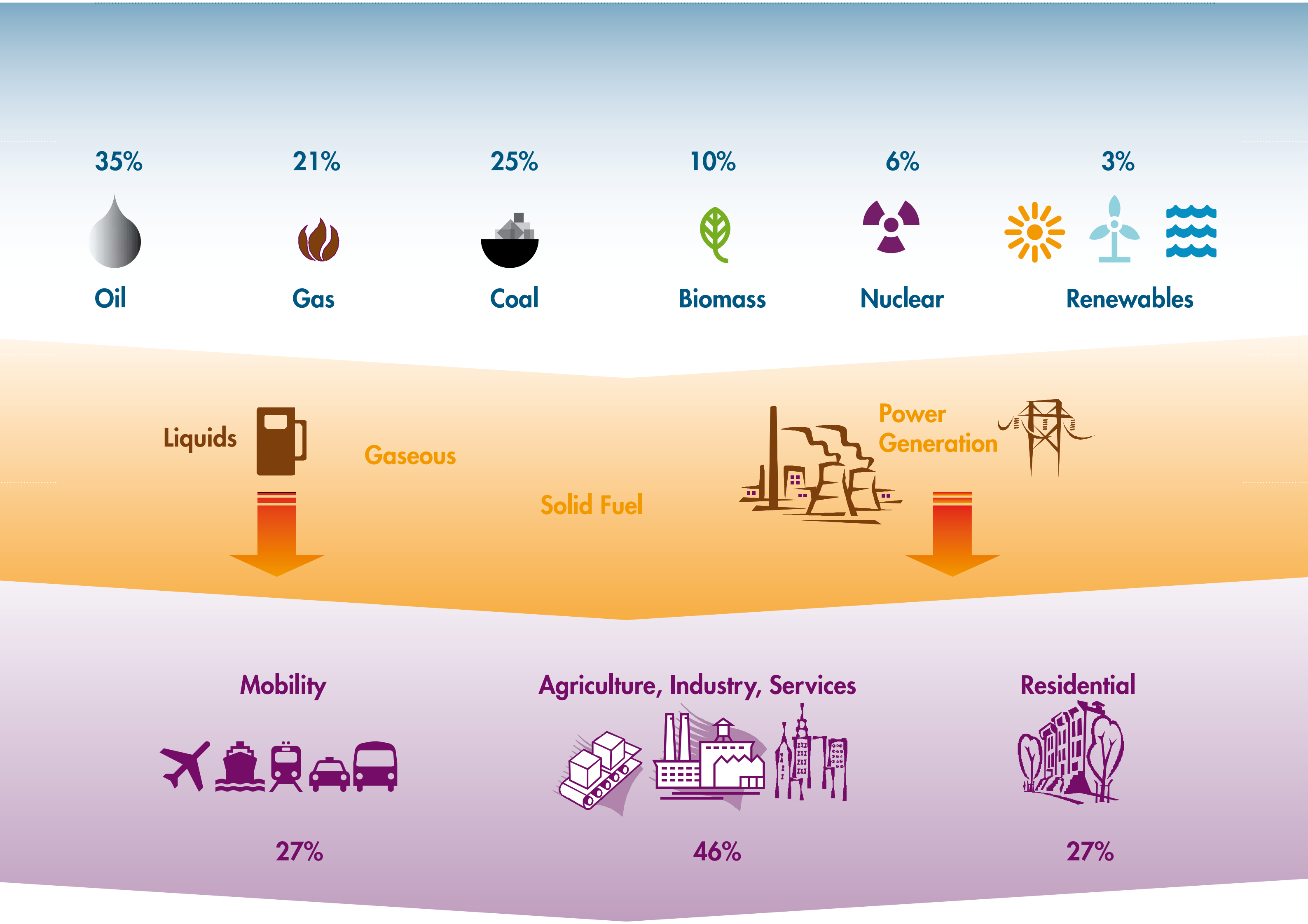
Primary energy resources are converted into a number of different energy carriers: oil into liquid hydrocarbons, coal into solid hydrocarbon fuels, wind into electrons, gas into liquids, or into hydrogen. As energy carriers differ in characteristics, they are measured in different ways (barrels, tonnes, watt-hours). The critical factor is the amount of energy available for use; so a common measure – joules – is used that allows comparison of energy efficiency across different carriers.

When comparing energy sources or carriers, it is important to consider a number of factors. These include: their "capacity factor" – the relation between average power delivered over a year and installed peak power; their dispatchability – the ability to start and stop generation at will; the ease of storing the energy carrier; and other characteristics such as end-use efficiency.

When assessing the relative performance of energy carriers, it also necessary to consider other inputs required to produce usable energy (such as raw materials, labour, land, water), the amount of contamination they may cause (waste water, radioactive waste, CO_2, etc.), and the associated amount of energy needed to deal with this contamination.

The complexity and cost of the infrastructure needed to use a given energy is perhaps the main factor that will determine whether and how fast a technology can develop to unlock additional energy resources and achieve mass-market impact. For example, hydrogen fuel, solar power and wind power all require different infrastructure investments before they can deliver significant amounts of usable energy.

The Energy System - Today[1]



Note 1: All data sources for charts and a glossary of abbreviations can be found on page 140

Global Warming

The ice ages in the distant past prove that climate can change by itself, and radically. Though not new, the belief that human activity can change the climate is a more recent understanding.

In 1896, Swedish scientists published a new theory called the "greenhouse effect". It argued that, as humanity burned fossil fuels that released carbon dioxide (CO_2) into the atmosphere, the planet's average temperature would rise. This is because the CO_2 absorbs heat radiated from the sun, trapping it in the Earth's atmosphere. Despite accepting the theory, the greater scientific community believed that major climate change would take tens of thousands of years to materialise.

By the 1930s, people realised that the United States and North Atlantic region had warmed significantly during the previous half-century. Scientists believed this was just a phase of some mild natural cycle, with unknown causes. Only one lone voice, G.S. Callendar, insisted that greenhouse warming was on the way.

In the 1950s, Callendar's claims provoked new studies that showed that carbon dioxide could indeed build up in the atmosphere and lead to global warming. Painstaking measurements drove home the point in 1961, by showing that the level of CO_2 was in fact increasing year by year.

A 1967 calculation suggested that average temperatures might rise a few degrees within the next century. However, with the next century far off, the calculations were plainly speculative. Scientists reviewing the issue saw no need for any policy actions.

Over the following decade, curiosity about climate turned into anxious concern. Study panels began to warn that future climate change might pose a severe threat and research activity accelerated.

Programmes were organised on an international scale and the world's governments created the Intergovernmental Panel on Climate Change in 1988. By 2001 this panel managed to establish a consensus, announcing that it was much more likely than not that our civilisation faced severe global warming.

Since 2001, the abundance of data has strengthened the conclusion that human emissions are very likely causing serious climate change. Depending on what steps people take to restrict emissions, the planet's average temperature might rise between 1.4 and 6 °C by the end of the century. Although only a small fraction of this warming has happened so far, predicted effects are already becoming visible – more deadly heat waves, rising sea levels, more frequent severe floods and droughts, the spread of tropical diseases and the decline of species sensitive to temperature changes.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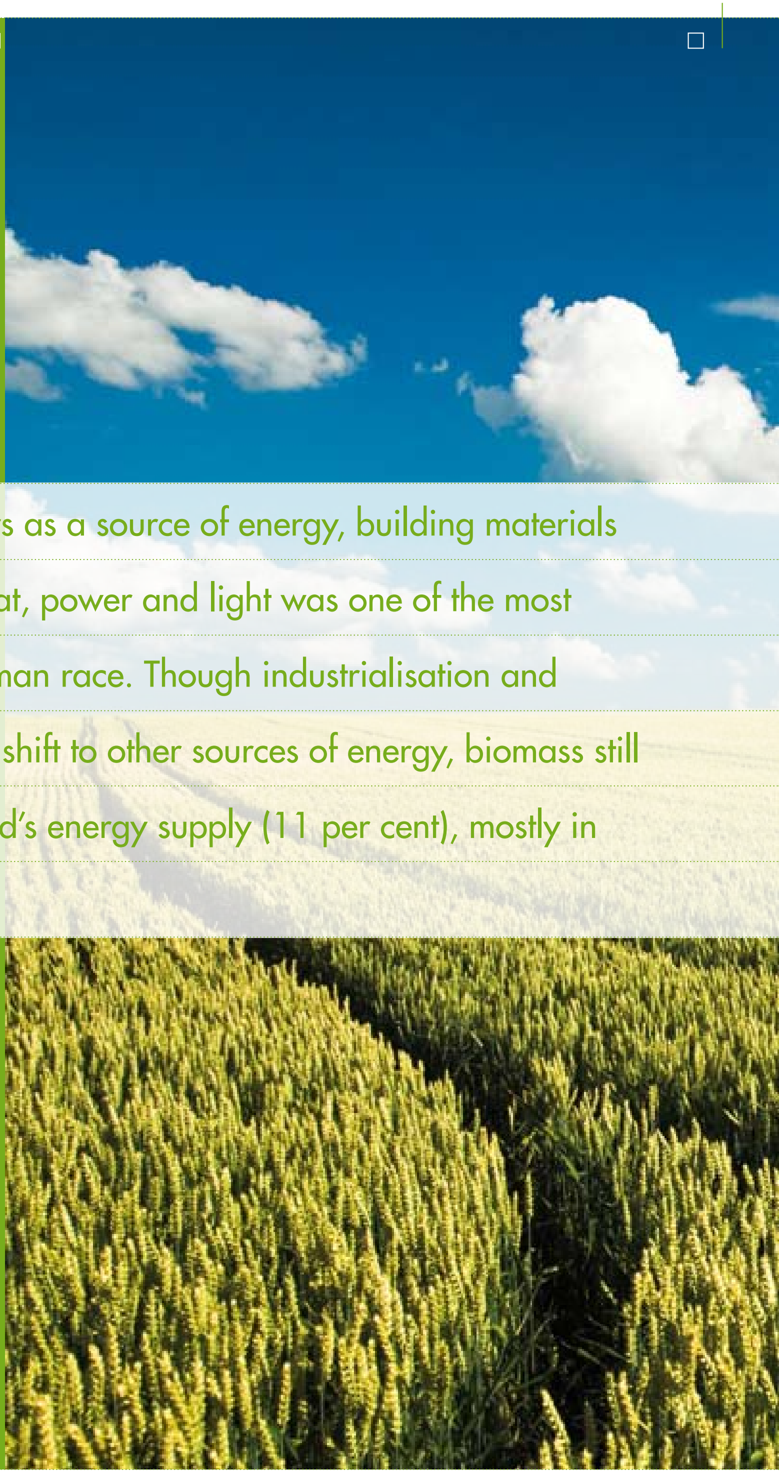
New Production Sources

Biomass

Biomass has been used for thousands of years as a source of energy, building materials and food. The discovery of fire to provide heat, power and light was one of the most important steps in the development of the human race. Though industrialisation and increases in income levels enable societies to shift to other sources of energy, biomass still makes up a significant proportion of the world's energy supply (11 per cent), mostly in rural areas of developing countries.



In the developed world, fuel derived from biomass – commonly called biofuel – is increasingly seen as an alternative to hydrocarbon fuels for the transport sector, and one that can help to meet growing demand and provide energy security. Because the range of crops and plants needed to produce it can be grown in many different countries and climates, biofuel is also prized as a way for some countries to boost domestic sources of energy at a time when concerns over energy supply are rising. As a result, demand for biofuels is growing rapidly but questions remain.

Can it be a viable large-scale alternative to oil? What challenges need to be addressed and is technology ready to respond?

"Harvesting an area the size of Texas could grow enough fuel to replace all the gasoline used in the USA."

So why doesn't the world just switch to biomass based fuels?

If only it were that easy.

Our assorted experts were able to agree on only a very few things. One of them was that biomass could provide an acceptable and affordable additional source of energy.

"Biomass can be grass, wood, agricultural waste, trash paper, anything organic that we are throwing away. Instead of throwing it in a landfill and generating greenhouse gases and methane we could convert that material into ethanol."

For at least a hundred years, scientists have been trying to find a commercially viable energy concentration system to rival fossilisation. Fermentation, the process that gives us beer, wine and spirits to drink, is one way to do it. Fermentation can make concentrated fuel from crops by turning organic plant material into sugar and then ethanol, often known as grain alcohol.

Our experts gradually formulated a clear and concise run-down on how biomass could virtually replace oil for mobility fuels – if given the chance. It emerged that the main problem may not be the availability of biomass.

"We can grow about ten tonnes of biomass per acre per year and get about one hundred gallons of ethanol per tonne of biomass. So we're talking about one hundred million acres of land, and by comparison Texas is one hundred and sixty seven million acres of land. So we are now talking about an area less than the size of Texas to replace all gasoline in the United States."

"There are about 2.3 billion acres of land in the United States so you're not talking a huge percentage, even if we go the worst possible route. We use about four hundred million acres of land in the United States for crops. But we have about one hundred million acres of land set aside land for agriculture and not used for agriculture. Those one hundred million acres are enough to produce all the fuel we need to replace gasoline."

But why use biomass for fuel?

"We tend to have a preference for liquid fuels, and as long as we like liquid fuels the only foreseeable way I can see to produce liquid fuels on a large scale at an economical price is from biomass. It's just a matter of figuring out the most economical way of converting biomass into liquid transportation fuels – because we're about 97 per cent dependent on liquid transportation fuels."

"Fundamentally there's no reason why you can't make fuels from biomass economically attractive. The trick is to bring down the cost of conversion. It's more of a conversion problem than a feedstock problem. I'd rather have a conversion problem because a feedstock problem would be much harder to overcome."

Is it now, as some people claim, cheaper to grow liquid fuel than to refine it from crude oil; or is biofuel still more expensive than petroleum?

There is no hard answer because no one can say how much petroleum really costs and how much it really costs to grow and process bio fuel.

"All direct price comparisons are confused by taxes and subsidies. Oil palms are the cheapest source of plant oil. Palm oil pricing comes close to oil when oil is fifty dollars a barrel. But palms grow best in the tropics and draw huge amounts of water - where water is most scarce."

Will the oil industry be ready to meet mass demand for biofuels?

"It is hard to get an accurate fix on just how much money the oil companies are investing in making biofuel a replacement for fossil fuel. The way oil industry analysts work, any investment of less than half a billion dollars is rounded down to zero. So investment in biofuel needs to be above half a billion to be noticed."

Biofuel

When Henry Ford was designing the Model T motorcar, a hundred years ago, it famously came in any colour...as long as it was black. But it could run on either gasoline or ethanol. In those days oil was plentiful and the USA had it in abundance, so gasoline won out. Now oil is a lot less plentiful, much more expensive and comes mainly from the Middle East. So ethanol is looking far more attractive than it did in Ford's day.

Ethanol is already widely used as vehicle fuel in Brazil and is increasingly popular in the USA. Because of the design of car engines, ethanol must usually be blended with gasoline. Although many existing car engines will operate on E10 – a mix of 10 per cent ethanol and 90 per cent gasoline – higher concentrations of ethanol need a modified "flexible fuel" engine.

"In order to generate sufficient mechanical energy from the biofuel, the engine needs a higher compression ratio and the seals need tightening, but that's not too difficult." "But do-it-yourself modification of a car engine to let it run on biofuel voids warranties."

Ethanol is less efficient than gasoline, producing around one-third less power. However engines can be designed to burn ethanol more efficiently, with a higher compression ratio, to compensate for the loss of heat energy and deliver much the same power. High-compression engines will only run on pure ethanol, though. And because ethanol and gasoline are chemically very different, ethanol fuel will need a completely new distribution infrastructure too.

First Generation Biofuel Production

The term "first generation" refers to biofuels that are made from starch and sugar using fermentation technologies available today. It also includes fuels that are made from vegetable oil and animal fats. The two primary biofuels in use currently are ethanol – which accounts for 90 per cent of total biofuel production – and biodiesel.

Biofuels are an attractive alternative to fossil fuels because – in theory at least – they do not contribute to the level of carbon in the atmosphere. In the case of ethanol, for example, the plants that are used to produce the fuel absorb roughly the same amount of carbon dioxide from the atmosphere while they grow as is produced when they are burnt as fuel.

Ethanol is produced when microbes and yeast ferment sugars present in crops. The sugars can be directly extracted from crops such as sugarcane or derived from the starchy parts of crops such as corn (maize). The yield from the process varies depending on which crop is used: for example cornstarch produces about half the yield of sugar cane.

Ethanol is then blended with gasoline for use in existing vehicles. Production of first-generation ethanol is increasing fast. Global fuel ethanol production more than doubled between 2000 and 2005, while production of biodiesel, starting from a much smaller base, expanded nearly fourfold.

Biodiesel is a replacement for standard diesel and is made from biological sources such as vegetable and animal fats. Diesel engines were originally designed to run on unprocessed vegetable oils, and modern diesel engines are still able to do so. However, in colder climates some engine modification is necessary to make sure that the unprocessed oils remain fluid.

The majority of biodiesel is made by means of a process called transesterification, which uses ethanol or methanol to alter the chemical composition of the starting compound (vegetable or animal oils) into a form, that can be used in unmodified diesel engines. Currently, Germany produces the most biodiesel in the world, followed by France. ■

"Who will risk buying a bio-only car until every filling station has bio pumps? No one wants to risk owning a car which leaves them stranded miles from a filling station that stocks the right kind of fuel."

"Existing pipelines won't do. Water gets dissolved in the fuel. You need special pipes and seals. But all that's solvable, too."

"But who can expect every filling station to install bio-pumps until there are enough bio-fuelled cars on the road to justify the investment and commitment?"

It's the classic chicken and egg circle that the home entertainment industry has faced every time it tries to launch a new disc or tape format. No hardware, no software, in a vicious circle that can only be broken by subsidies that encourage the hardware makers and software suppliers to commit.

Brazil provides an example of how it can be done. Biofuels have grown to command a significant share of the fuels market because industry and government have worked together towards a solution. Over half of all new cars sold there today are "flex-fuel" vehicles able to run on any combination of gasoline and ethanol, which is produced from sugar cane that grows in abundance in Brazil's hot, humid climate.

"The good news is that, unlike a switch from driving on the left to driving on the right, the transition to biofuel can be gradual."

There turned out to be plenty of room for argument on the benefits to be had from running a car on biofuel. The engine emits about as much CO_2 as when it is run on fossil fuel. But whereas burning fossil fuel releases CO_2 trapped by plant growth millions of years ago, burning fuel from recently grown crops is only releasing the carbon dioxide they absorbed from the air as they grew. So the biofuel grow-and-burn process is carbon neutral - in theory at least.

"When you burn ethanol you generate CO_2 but plants take up CO_2; so as long as you grow a new blade of grass to replace the one you converted into ethanol, you just take back the CO_2 that you released and turn it into a new blade of grass. So it's a closed cycle which is different from fossil fuel where we're taking the carbon from under the ground and putting it in the air."

There was clear consensus on one simple commercial way to hedge bets for the future. When we buy a new car we should be offered the option of a "flexible fuel vehicle", or even the new variable compression ratio engines that can cope with any fuel mix. The chances are that we aren't. As most people keep their cars for at least five years, the chance to burn greener fuel is lost for another five years with each gasoline-only car sold.

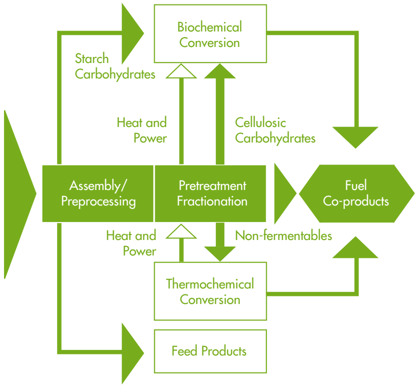
©Bosch

Flexible-Fuel Cars

As the name suggests, flex-fuel cars can run on more than one source of fuel. Commonly, they have engines capable of using a mix of ethanol and gasoline. Most modern cars are already capable of operating on fuel that contains a 10 per cent mix of ethanol – known as E10 – without the need for any engine modification.
Many vehicle manufacturers now offer specially adapted engines that can run on an 85 per cent blend of ethanol and 15 per cent gasoline known as E85. In Brazil, which has invested heavily in commercial ethanol production, the common fuel mixture at petrol stations is E25.

In addition to running a blend of fuels, it is now possible to have a vehicle with different types of fuels in separate tanks. In 2006, Bosch launched an engine management system that allows cars to switch seamlessly between fuels without interrupting engine performance. The system will operate on compressed natural gas (CNG), gasoline, or ethanol.

Technology developments such as these are likely to ease the transition between a transportation system powered by gasoline and one that is powered by alternative fuels. ■



Biorefineries

The concept of the biorefinery has its roots in the modern oil refinery, and describes a highly integrated number of individual processes that convert biomass into biofuel, power and a number of high value co-products.

The US National Renewable Energy Laboratory defines a biorefinery as :

"...a facility that integrates biomass conversion processes and equipment to produce fuels, power and chemicals from biomass. The biorefinery concept is analogous to today's petroleum refineries, which produce multiple fuels and products from petroleum."

The parallels with oil refineries mean biorefineries can draw upon decades of technology development, helping to reduce the overall cost of producing biofuels and encouraging their development. However, in contrast to fossil fuel deposits such as oil fields, the relatively dispersed nature of agricultural crops and the high cost of transporting solid biomass will put upper limits on the scale of future biofuel plants.

It is unlikely that biorefineries will be in full-scale production before 2020 due to the time needed to construct plants and adapt or develop the necessary technology, and because of the large capital investments required.

"There should be a lot more encouragement when we are buying a new car to choose one with a bio-capable engine – the same kind of encouragement as today's salesmen use to sell cars with power-hungry air-conditioning."

Flex-fuel engines are much easier to design now that cars rely on computer controlled engines, which can detect what fuel mix is in the tank and automatically adjust the injection mix of fuel and air to suit the fuel type and ensure that the fuel burns cleanly in the engine.

"Tuning a car over the weekend with a spanner, screwdriver and keen ear used to be a male rite of passage"

Car enthusiasts who mourn the passing of this rite can at least take comfort from the knowledge that electronic engines are helping the world find an alternative to oil.

What happens in the lab can take a long time to reach the market, though. Electronics manufacturers already complain that it takes automakers at least five years to change their in-car entertainment systems from tape to disc, or MP3, and provide digital radio reception.

"Without a shock to concentrate minds, the bio-transition will be painfully slow."

Even experts can be coy about suggesting the kind of shocks that might do the trick. And when they are all in the same room at the same time, conflicts of opinion quickly emerge and a number of obstacles and drawbacks are identified that have to be overcome before biofuels fulfill their potential.

Second Generation Fuels

In order to expand the types of biomass that can be converted to fuel and so increase biomass availability and avoid direct competition with food, work is underway to develop a new range of so-called second-generation biofuels. Second generation conversion processes can produce ethanol from cellulose – the main constituent of plant cell walls and of vegetable fibres – and plant fibre such as waste corn stalks, straw and woodchips. It does not, therefore, use the food component in plants and crops. Chemically, cellulose ethanol is identical to conventional ethanol.

"The first cellulose ethanol extraction plants are now working, but they are only pilots. Government certification can take up to seven years."

New powerful enzymes are needed to separate the cellulose from the rest of the plant. What's left is lignin, which can be burned to drive the entire cellulose ethanol production process by generating steam and electricity – eliminating the need to use fossil fuels such as coal or gas.

"Genetic modification of plants and bugs could solve most of the chemical problems, but GM has had a very bad press."

Ethanol can also be synthesised from oil. So how is a consumer – already suspicious that some "organic" meat and vegetables and "free-range" eggs may actually be coming from factory farms – to know whether fuel from a filling station pump has come from "green" crops or fossil oil?

Synthetic Organisms

Producing ethanol involves complex chemical reactions and requires micro-organisms that are able to tolerate ever-changing conditions during these reactions.

At present, different microbes are used at different stages of the process. To accelerate the commercial development of second-generation biofuels and biorefineries, work is now underway to reduce the number of microbes thereby simplifying the process and reducing overall cost.

Currently, there is no single microbe that can turn biomass into ethanol in one step. The ideal organism would be capable of breaking down cellulose like a bacterium and fermenting sugar like yeast, while at the same time tolerating high concentrations of ethanol, and producing pure ethanol.

There are two approaches to solving this problem. The first is to genetically modify an existing organism while the second, more radical, approach is to engineer an entirely new organism. Far from being the realm of science fiction, the latter approach is being pursued by several research groups who are aiming to create a bacterial cell whose genome – the complete set of genetic material present in the cell – is totally synthetic. ■

Second Generation Biofuels

Second-generation biofuels are made from the entire plant, instead of just parts of it like first-generation biofuels. The process uses plant fibre, such as corn stalks, straw and potentially woodchips. It has a much better energy yield, and does not compete for the world's food supplies.

Although the processes for producing first and second generation biofuels are very different, the ethanol produced is chemically identical to that produced using first generation technologies. So no new distribution infrastructure or engine modification is required to use it.

More work still needs to be done to make second-generation biofuels commercially viable. Cellulose requires a fundamentally different and more sophisticated approach to releasing the energy stored within. A multitude of specific enzymes are used to break down the many different sugars in a plant and separate them from the rest of the plant. A pre-treatment step increases the surface area of the plant fibre for the enzymes to act upon. The plant's lignin, which provides strength and is an excellent fuel, is burned to drive the production process by generating steam and electricity – eliminating the need to use fossil fuels such as coal or natural gas. Much of the current research in this area now focuses on simplifying the number of steps in the process and reducing the cost of enzyme production – one of the major costs in second-generation biofuel production.

Genetic engineering has been a key enabler in this business, and has led to the development of micro-organisms that make second generation biofuel production a commercially viable proposition.

There are a number of pilot plants already in operation for the production of second-generation ethanol. Commercial production, however, is unlikely to begin until the end of 2007 when new large-scale ventures are expected to come into operation. An additional blocker to the development of commercial second generation biomass-to-liquid processing plants is the level of investment needed to construct the plants and associated infrastructure. Developing robust industrial processes for the production of second-generation biofuels is critical to the development of biorefineries.

"Tracking and tracing the true origin and movement of goods is going to become increasingly important in the future if consumers are to trust what they read on labels."

Waste woodchips and straw can also provide the raw material to produce another substitute for gasoline: biodiesel. There are several steps in the production process. Biomass is gasified by heating it, first at low temperature to create a charcoal-like substance, then at high temperature to produce tar-free synthesis gas. The gas is then converted into sulphur-free synthetic fuel using the same process that converts natural gas into liquid fuel. Algae could well be the ideal plant life for making biofuel as it has the potential to be grown in large volumes without using agricultural land and it is easier to transport than land-based biomass.

"But if the algae are farmed in the open sea, a storm can wipe the whole system out."

"We've messed up the land and air. Now we are starting on the sea. Letting algae grow too freely takes oxygen out of the water, which kills fish. The world doesn't need lettuce. Better to grow biofuel instead of lettuce."

In Holland, sea salad is being grown in inland salt-water basins, along with oysters and mussels. The basins could be used for farming algae for fuel instead. So the choice between fuel and food rears its head once again.

Societal Factors

Changes in society, rather than advances in technology alone, will dictate how fast biofuels take off.

"Technology is not the issue. Fuel farming for the whole of North America's needs would occupy less than 10 per cent of the country. One-third of the world's arable land could grow enough fuel to replace all oil. If demand stayed static it could deliver 100 per cent of oil requirement."

"But demand isn't static. It grows."

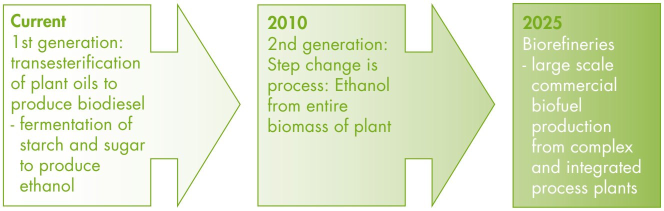
"The graphic display on a hybrid vehicle like the Toyota Prius is a fun way to see how fuel consumption is heavy during acceleration and low when the engine is harvesting energy when braking. This is changing the way some people drive."

It's a small effect though, confined to a small percentage of the driving population. Pride in fuel efficiency won't convert the masses. It won't sell bio-capable cars either.

So what would encourage car salesmen to try and sell us a flex-fuel vehicle?

"That's easy. Lower taxes on the vehicle and fuel."

Tax breaks and subsidies would certainly encourage car manufacturers to make more flexible fuel or variable compression ratio engines, and more drivers to buy them. This can then help to drive the cost curve down over time and as the technologies come down in price so the need for subsidy reduces.



Owners of electric and hybrid vehicles in the U.K. can currently escape some parking fees and the congestion-charge tax on driving into central London. Press the right accounting buttons and there are tax credits to be had from buying the car, too. The schemes can be extended to cover cars that use biofuels. When will the exemptions cost too much to continue? When the cars that aren't paying are outnumbering those that are paying, perhaps? By then, though, there will be no turning back. Green fuel will be on sale as widely as diesel.

For biofuel, it emerged there is a constraint for every benefit – and a benefit for every constraint.

Mother Nature seems to have come up with a rule of thumb for biofuel production. The easier it is to convert a plant into ethanol, the less ethanol the crop will produce. In Brazil, the climate allows easy growth of sugar cane as the main ethanol crop – in the USA mostly maize corn is grown. Maize corn is easier to convert into ethanol than cane but has half the fuel yield. Switch grass is more difficult to convert but yields nearly twice as much ethanol as cane.

There are other potential drawbacks too. Growing crops requires fertilisers - fossil fuels may be used in the production of those fertilisers, offsetting some of the benefits of using biofuels as a substitute for gasoline in the first place. And if you use intensive farming methods to grow the source crops to produce biofuel, you risk damaging valuable arable land.

"When you have grown the material it has to be harvested and taken away for processing. That costs more energy."

"The crops are chosen because they ferment easily. In fact they ferment so easily the problem is stopping them while still in storage or transit."

"Existing bio-conversion systems have to be big. So only big companies can afford to build and run them. The goal is simplicity and local production to cut down on transport. Install a vat, throw in some secret sauce and come back next day. If the design is right it won't need heat or higher pressure."

"Farmers can earn seven times more from growing maize for car fuel than for food. Twenty-five per cent of corn grown is now being used for ethanol production. In Mexico the price of tortillas has already gone up because the US is growing maize for fuel. In the future there will be more choices to make. Will a village in India grow food for the villagers or fuel for cars in America?"

"The problem is the press isn't particularly informed and does a pretty miserable job overall in terms of getting accurate news. I saw a headline about a specific problem with burning palm oil which implied that all biofuels are bad."

"Displacing people raises human rights issues. In India, where 50 per cent of economic activity is based on agriculture, land is owned by tribal groups."

Growing populations will magnify existing conflicts over land use – food growth versus fuel crops, useful production at the expense of recreation, wilderness or managed land. And more land will be needed for planting trees to offset carbon emissions.

Increased Yields

While advances are being made in the biomass-to-ethanol conversion process, there is also a considerable body of work underway that has the potential to double the amount of biomass that can be harvested from a given area of land.

Advances in plant breeding and plant science are expected to help double current plant yields to fifteen tons per acre a year by 2030. "Smart" agriculture – through the use of GPS, satellite imaging and more accurate weather forecasting – is expected to be available to the majority of the world's farmers by then as well. This will have a significant impact on production by enabling improved farm management that recognises specific local conditions resulting in further improvements in yields.

The table outlines further advances in key aspects of plant biology that will affect biomass production. For each type of scientific advance – such as the ability of plants to self-fertilise – the table shows the collective views of our experts on the time it will take before these techniques are in widespread use around the world.

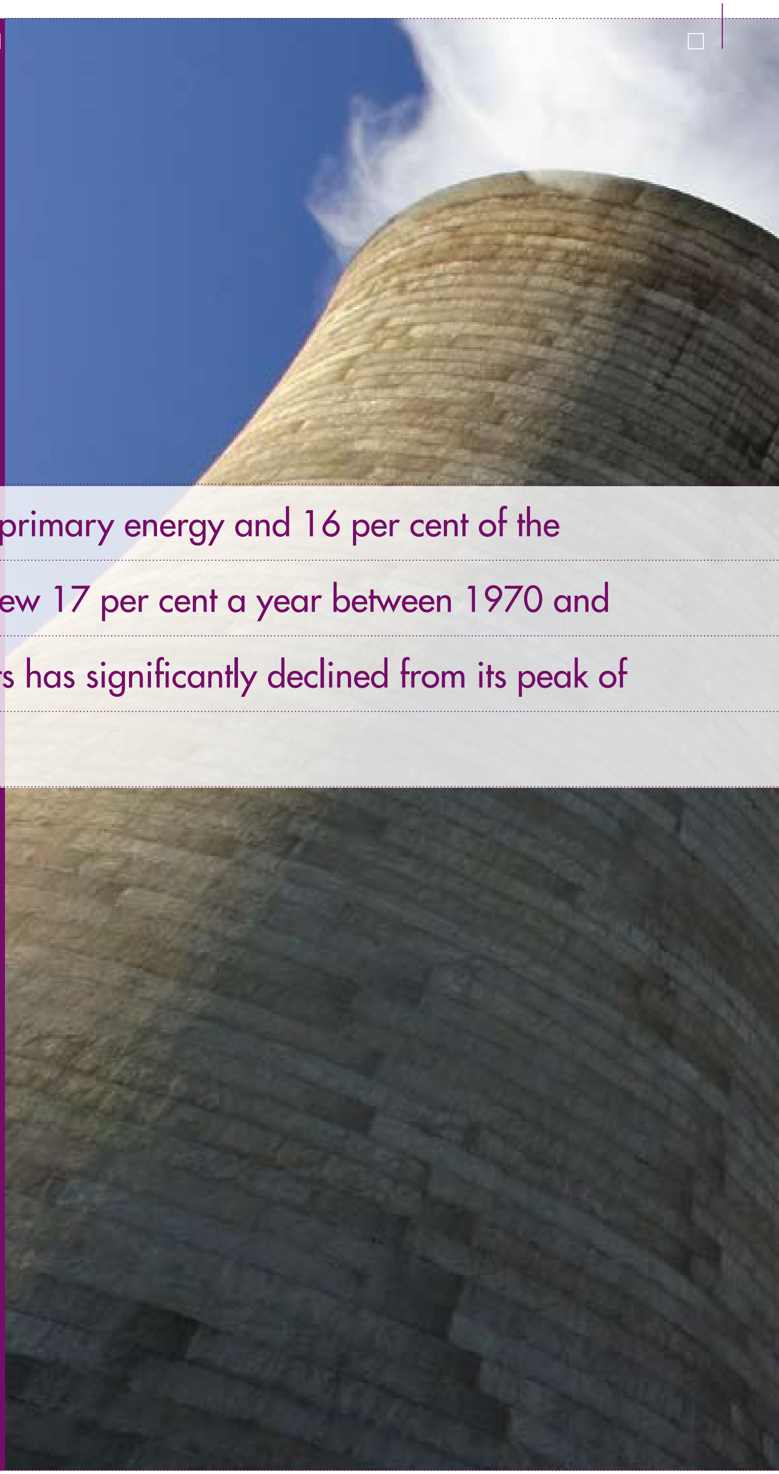
Biomass Production

		Year		
Area	**Technologies**	**2010**	**2020**	**2030**
Self-fertilising	Plant breeding	0%	80%	100%
	Plant science			
	Genomics			
Drought tolerant	Plant breeding	0%	60%	100%
	Plant science			
	Genomics			
Insect resistance	Plant breeding	0%	60%	100%
	Plant Science			
	Genomics			
Salt tolerance	Plant breeding	0%	30%	100%
	Plant Science			
	Genomics			

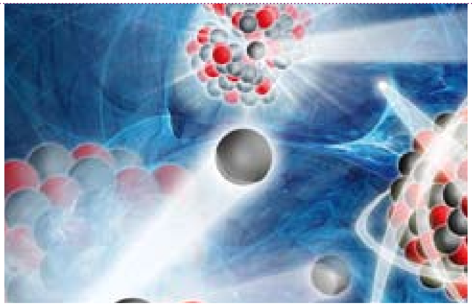
New Production Sources

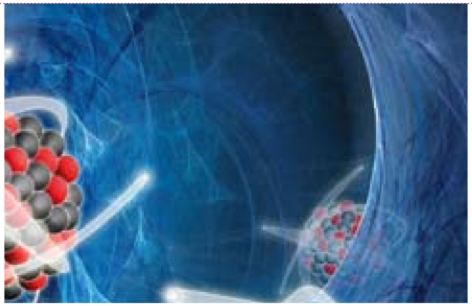
Nuclear

Nuclear power accounts for 6 per cent of all primary energy and 16 per cent of the world's electricity. Global nuclear capacity grew 17 per cent a year between 1970 and 1990 but construction of nuclear power plants has significantly declined from its peak of 200 GW installed during the 1980s



Like coal-fired power generation, nuclear power provides base-load power and hence operates at near capacity all of the time. In comparison, oil and gas power plants are typically load-following due to their ability to respond quickly to fluctuations in demand. Once constructed, nuclear power plants produce electricity with near-zero emissions of CO_2 – a tantalising prospect at a time when concerns over energy supply and climate change are on the rise. Development of an effective pricing mechanism for CO_2 would effectively lower the cost of nuclear plants, potentially providing a renewed impetus for growth. Nevertheless, fears linger over the safety of nuclear power following a number of serious accidents such as the Ukraine's Chernobyl disaster in 1986. And much of the world's existing nuclear energy capacity is ageing and will require replacement in the near future. So what are the prospects for the development of nuclear energy in the coming decades?





Nuclear Power: Fission

Nuclear fission is the process of splitting atoms. In a nuclear power plant, fission is undertaken in a controlled way – unlike in a nuclear bomb – in order to harness the energy inside the atoms and convert this energy to electricity. Fissile isotopes are isotopes of an element that can be split through fission. Only certain isotopes of certain elements are fissile. Uranium is the principal element used in nuclear reactors.

The nucleus of a uranium-235 atom consists of 92 protons and 143 neutrons. When a U-235 atom absorbs an extra neutron it becomes unstable and will split. The products of the splitting of the nucleus, the largest of which are called fission products, have a total mass that is less than the original mass of the uranium atom. The lost mass is converted into energy. Not all forms of uranium are fissionable. U-238, for example, is not fissionable but can absorb neutrons and form plutonium-239, which is indeed fissionable. In a nuclear power plant almost half of the heat energy produced comes from P-239, even if there is none of it to begin with.

A nuclear power plant works in the same way as a conventional fossil fuel power plant, using the heat generated to boil water, produce steam and generate electricity. The most common type of reactor is the Pressurised Water Reactor (PWR).
A nuclear power plant uses much less fuel than a comparable fossil fuel plant – around 1 kilogram of nuclear uranium fuel can produce the same amount of electricity as 17,000 kilograms of coal. Typically the fuel is contained in fuel rods containing uranium that has been mined, refined and purified. The most significant use of nuclear reactors is as an energy source for the generation of electricity and to power some ships. This is usually accomplished by methods that involve using heat from the nuclear reaction to power steam turbines.

Past and predicted future developments in the evolution of fission-based nuclear power are summarised below:

Generation/Year	Stage	Reactor Types
1 1950 to 1965	Early prototype	Magnox
2 1965 to 1993	Commercial power reactors	Light water, pressurised water, advanced gas, boiling water
3 1993 to 2008	Advanced light water reactors	Advanced boiling water, evolutionary pressurized water reactor, advanced passive
3+ 2008 to 2027	Evolutionary designs	Pebble bed modular, intrinsically safe, innovative concept
4 2027 to ...	Evolutionary designs	Gas cooled fast, very high temperature, supercritical water cooled, sodium cooled fast, lead cooled fast, molten salt

Fission

Powering the power stations.

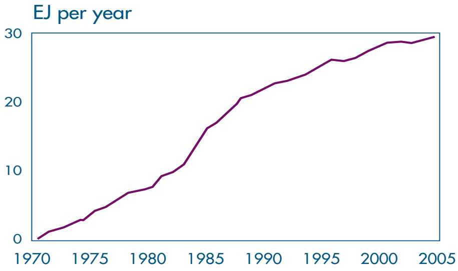
In the 1950s atomic energy was the next big thing, hailed as a miraculous source of endless, clean energy. Harnessing nuclear power to create a slow reaction – using a process known as fission – rather than a rapid and explosive one was seen as a wonderful new way to generate heat, boil water and use the steam to drive turbines that generate electricity. Nuclear power required only small amounts of fuel and generated no smoke or smog. Construction began on nuclear power plants around the world.

Atomic energy was popular with the public too. Even atom bombs had a good press. When the US government tested nuclear devices in the desert near Las Vegas, barmen started to mix Atomic cocktails and beauty salons offered Atomic hairdos. Because the fiery flashes, loud bangs and broken windows could hardly be kept secret, the authorities started to announce dawn tests in advance. Gamblers partied all night and went up on the roof to watch the show, like a fireworks display.

But the love affair with nuclear didn't last as a series of accidents knocked confidence in the technology. In 1957, a fire broke out at the U.K.'s Windscale and Calder Hall plant, the world's first commercial nuclear power station. The reactor had only started generating power a year earlier, when the incident destroyed the core and released radioactive material into the atmosphere. Milk and crops had to be destroyed. Later the plant was renamed Sellafield, but the memories linger on.

In 1979 a non-fatal accident at a reactor at Three Mile Island in Pennsylvania further eroded confidence. As society grew more concerned, popular fiction reflected people's fears. The 1979 movie "The China Syndrome" fictionalised a meltdown in which a reactor core burns down and through the Earth's crust. In another movie, 1983's "Silkwood", Meryl Streep dies in mysterious circumstances when she tries to blow the whistle on lax procedures at a nuclear facility.

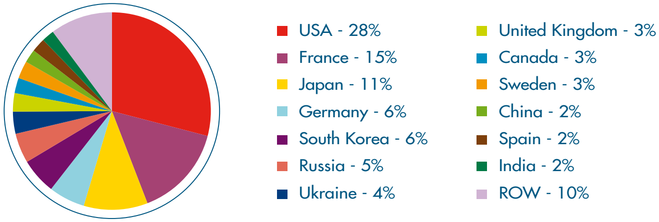
Nuclear Energy (Fission)



But it was when the Chernobyl nuclear plant in the Ukraine exploded in 1986 that the consequences of a nuclear disaster became apparent. The catastrophe released radioactive material across an area that is still uninhabitable today, and sent a radioactive cloud over much of Europe. Thousands died and untold numbers are still suffering the devastating health affects. It's not surprising, therefore, that during the 1990s there was a lot less public enthusiasm for building new nuclear plants. Just as politicians now have to talk "green" about global warming, if they want to stay in politics, they have had to be very careful about advocating new nuclear power plants.

But the pendulum is swinging back. "People don't say it too loudly but a lot of today's electric power already comes from nuclear plants. They are getting old and will have to be shut down. The power they are contributing will have to come from somewhere – or our lights will go out. Coal is dirty. Europe is relying more and more on gas from Russia. Do we want be in that position? The current state of play on wave, wind and solar schemes means they can't fill the gap. Nuclear power is starting to look like the best option again."

Nuclear Fission Power Generation Today



The public is now so aware of the environmental damage that can be done by coal-burning plants that the idea of nuclear power is finding favour again in some quarters. Soaring energy prices and headline news about political instability in the Middle East have made it much easier for governments to discuss the possibility of building new stations.

"Finland is now building a new nuclear power station even though the country was in the wind path from Chernobyl and was hit by fall-out," the group was reminded. "The country already has four nuclear reactors providing 27 per cent of its electricity; a fifth was approved by the government in 2002 and is already under construction for a 2011 start-up. Finland plans to be completely independent of oil within ten years. Energy is Finland's new Nokia."

"Is nuclear really so bad?" one of the group mused provocatively. "Dirty water kills five million people a year. A nuclear event is just two years of dirty water."

Nevertheless, significant worries remain. Newspapers have run shock reports on nuclear waste from power plants being shunted round the world in search of a country which can be paid to store or bury it somewhere "safe" until a long-term solution is found.

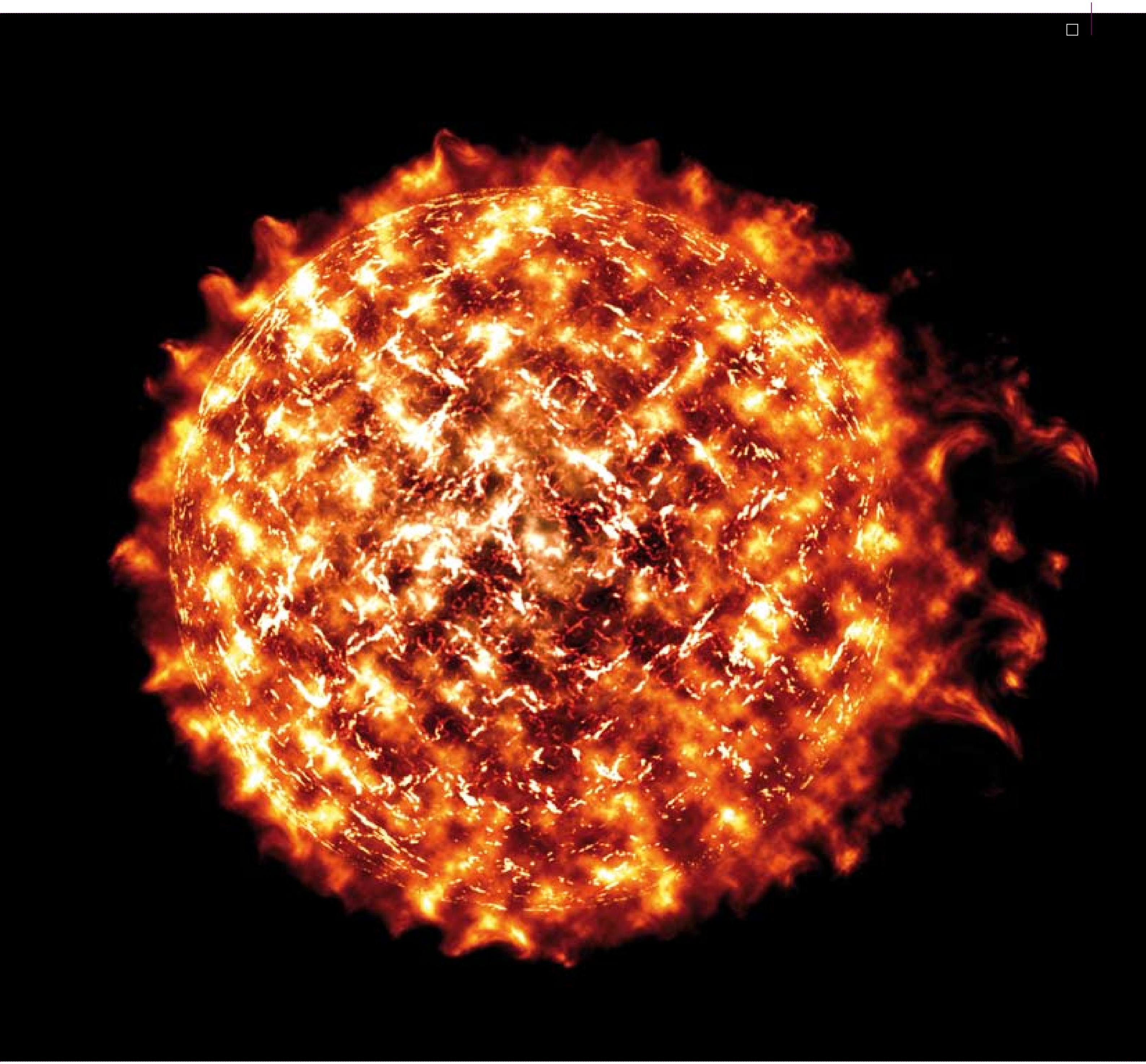
Concerns about the risk of nuclear terrorism are more recent. "People talk about the risk of losing radioactive material from Russia and the need to track it. Well, a lot of it has already gone missing."

There was general agreement that companies will remain reluctant to invest the large amounts of money required to build new capacity without greater certainty about the regulatory environment, potential economic returns and liability costs associated with disposing of nuclear waste. This, when combined with continuing public debate over the pros and cons of nuclear fission and the long time-lag from investment decision to full operation, will limit the growth of nuclear power unless and until governments provide the assurances that the private sector needs to overcome its concerns.

Nuclear Power: Pebble Bed Reactors

The basic principle of a pebble bed reactor is a combination of two design features: the gas cooling of the core and novel packaging for the fuel that dramatically reduces complexity, while improving safety. The fuel packaging encases uranium in billiard-ball-sized graphite pebbles that cannot get hot enough to melt within the small core. The packaging also allows long-term disposal without reprocessing.

The pebbles are held in a bin or can. As the reaction occurs, an inert gas – helium, nitrogen or carbon dioxide – circulates through the spaces between the fuel pebbles to carry heat away from the reactor. This overcomes the need for the large-scale cooling systems and safeguarding systems required by water-cooled nuclear power plants. As helium the preferred gas, does not easily absorb neutrons or impurities, it is more efficient and less radioactive than water. The absence of hydrogen in the coolant reduces the need for maintenance and replacement of embrittled piping.



Fusion

If these obstacles can be overcome, what might the nuclear industry of the future look like? In 1989, Professors Stanley Pons and Martin Fleischmann caused a media storm by claiming to have discovered a new way to produce clean cheap nuclear energy using a process called fusion. If correct, their discovery holds the potential to transform the global energy scene.

"Fusion is the dream. Very low fuel costs give virtually free electricity. So near free transport, too. It would mean the collapse of the Middle Eastern economy. There would be a lot of very cross people in those countries. Cheap energy would cut off the money supply to the Middle East. But it could take thirty years to build a full-scale fusion reactor. That time scale may look short when you look back through the telescope of history, but living through it would look like a long time. Fusion is CO_2 free."

But conclusive scientific evidence to support the discovery of fusion has proved elusive and far more research still needs to be conducted. One of our experts related his experience of working on fusion:

"We ended up unable to say whether the effect is real or not real... Work, at least publicised work, ceased. There was no clear evidence to believe in cold fusion but not enough clear evidence to disprove the theory. Taking the work further will need people who know electrochemistry and can measure nuclear events.

"It's still an open question. There have been plenty of negative reports. But I never saw anyone who made a negative report who was competent to make a negative report.

"If you want the full story, look at the papers published by Dr. Edmund Storms."

"What's needed is a Manhattan project for fusion," reckoned another of our experts – referring to the US government programme to fund research to produce the first nuclear weapon during World War II.

"No-one is even talking about it. The Apollo moon-shot programme was just engineering, but with fusion we don't know how to do it. We don't know if cold fusion works. But it may work. So why is there no Manhattan project on fusion at least starting?" ■

Nuclear Power: Fusion

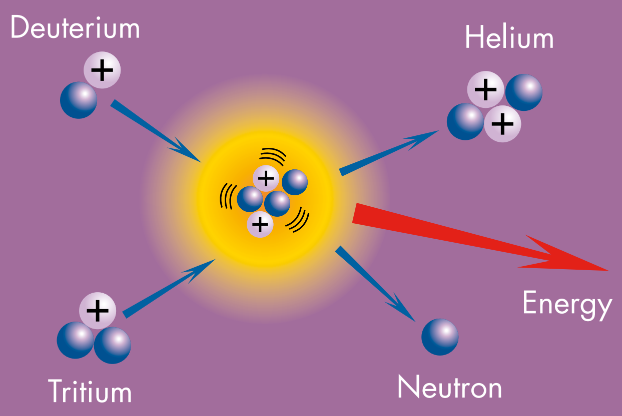
Fusion is the exact opposite of fission. While fission splits apart large atoms, fusion joins together small atoms. In a fusion reaction, two light atomic nuclei fuse together to form heavier ones, as shown in the illustration. As all nuclei have a positive charge due to their protons, fusion is very hard to produce because it requires an incredible amount of heat and energy to stop the two positively charged nuclei from repelling each other. The fusion process, when achieved, releases more energy than it took to force the two nuclei together, and this starts an exothermic process that can produce self-sustaining reactions.

The sun produces fusion at temperatures of 15 million K (kelvins); hydrogen is fused into helium, releasing massive amounts of solar energy – enough to support life on earth millions of miles away.

The European Union, the U.S.A., China, Russia, Japan, India and South Korea are co-operating to build a giant fusion reactor.

Called ITER – an acronym for International Thermonuclear Experimental Reactor – it is located in France, will become operational around 2020 and will cost US $10 billion dollars. If successful, the next step will be to construct the first demonstration power plant. This would be operational in the period 2040 to 2050. ■

Graphical representation of a fusion reaction (ITER project)



New Production Sources

Solar, Wind & Wave

Energy, energy everywhere and all for the taking – but how best to take it? Harnessing the abundant, clean “renewable” energy that is available from the wind, waves and sun’s rays could provide enough power to run the world. But finding cost-effective ways to do so remains a challenge. At present much renewable energy is still uncompetitive compared with hydrocarbons such as oil, gas and coal. Taken together, all renewable sources of energy being used today still only account for 3 per cent of global supply.

Breakthroughs in energy storage, transmission and demand-side management may help to remove some of the constraints that have historically limited the growth of renewable energy. The motor industry’s work on electric cars, and government subsidies on their purchase and use, should drive down the cost of batteries while improving their performance.

And recent developments in superconductivity that dramatically cut the amount of power lost through connection cables could radically improve the practical value of offshore wave-power generators and wind turbines installed out of sight and mind of homeowners. As one of our experts put it, however: “There is no single magic bullet”. After a day of discussion it was not hard to see why.

Solar

The sun is continually beaming abundant energy to the Earth as light.

"Global energy consumption is around 470 EJ (exajoules, or 10^{18} Joules) per year. The sun delivers to the earth almost 4 million EJ of energy. So theoretically the sun could provide at least eight thousand times the energy we need."

But how do people capture and exploit this abundant gift? One of the most common ways is to use sunlight to heat water. For many years most homes in Japan, and in most developed hot countries, have had solar water-heating systems on the roof. Simple-to-fit kits are easy to buy. The panels can warm water on dull days and even work in cold climates. To operate in winter temperatures they must be filled with antifreeze and work with a heat exchanger. Though this makes the system more complicated and fitting trickier, it remains effective.

The key factor that determines the take-up and competitiveness of solar energy is the efficiency of the panels in converting sunlight energy to electrical energy, which dictates the size and weight of the panel needed, and the production cost of the panel itself.

"Photo-voltaic (PV) efficiency is currently 20 per cent, probably soon rising to 30 per cent – compare that to photo synthesis which is 2 per cent efficient. In the long term all energy will be solar."

More details emerged as the discussions warmed.

"The best PV panels have a conversion factor of 19.5 per cent. The average is around 14 to 15 per cent. Cost is around a dollar to a dollar fifty per watt. The first generation PV was crystal. Second-generation thin-film PV is less efficient but cheaper. It has a conversion factor of between 5 and 10 per cent. The theoretical maximum efficiency is 86 per cent, while 40.5 per cent is the best so far achieved in the laboratory".



Solar Power

Solar power, or solar energy, comes from solar radiation emitted by the sun. For centuries, man has captured solar radiation, and converted it into useful power using a number of technologies. This conversion can be direct or indirect. Indirect solar power involves multiple transformations of sunlight, which result in a usable form of energy. Examples of indirect solar power are photosynthesis, wind, or wave energy. Direct solar power involves a single transformation of sunlight using a range of different conversion techniques and technologies – photovoltaics, concentrating solar power (CSP) or solar thermal – to produce a usable form of energy.

Photoconversion is a generic term describing the capture of light energy by a biological, chemical or electrochemical system for subsequent use as a fuel, a chemical or electricity. These technologies could be based on photosynthesis, plants algae or bacteria producing sugar or direct conversion in semiconductors: photovoltaic devices.

Concentrating solar power (CSP). There are three main types of concentrating solar technologies: trough systems, dish/engine systems, and power towers. Each uses a different configuration of mirrors to convert the sun's energy into high-temperature heat. The heat energy is then used to generate electricity in a steam generator. A key advantage of CSP is that the solar energy can be stored as heat before it is converted into power, which means that power can be generated outside daylight hours and dispatched when it is needed. CSP needs large-scale installations and thus competes in wholesale electricity markets at favorable peak daytime rates. The use of concentrated solar energy to generate higher temperature heat for industrial purposes is still in its infancy.

The ability of non-concentrating solar collectors to generate heat is relatively low (50 to 100 °C) and so is only suitable for use in low-temperature applications such as space heating in homes and greenhouses, hot water generation and pool heating. ■

"First and second-generation PV panels are here now, and third generation is in the lab. The option is either to increase efficiency by capturing and converting more wavelengths or to drive down the cost. The cost is now close to comparable with retail electricity. Lab efficiency is now around 45 per cent. There could be cells with 30 per cent conversion efficiency this year or soon after."

"The Holy Grail is a printed roll-up sheet. To drive development we need greedy investors, low interest rates and subsidies as in Japan and Germany."

But intermittency of supply remains the problem; when the sun goes in, the electrical output goes down.

"Variations in solar supply will really matter if 20 per cent of grid electricity is coming from solar panels."

Photovoltaics

A photovoltaic cell is a device that converts light energy into electrical energy. Sometimes the term solar cell is reserved for devices intended specifically to capture energy from sunlight, while the term photovoltaic cell is used when the light source is unspecified.

Compared to energy conversions for hydrocarbons and biomass, photovoltaics have a much higher information technology content, as the two primary components of PV cells are the solar panel (which converts energy from the sun into DC electricity) and the solar inverters (which convert DC to AC electricity for wider use).

At present, photovoltaic panels typically convert about 15 per cent of incident sunlight into electricity. Therefore, a solar panel typically delivers 100 to 150 watts per square metre at peak sunshine or 100 to 150 kilo watt-hours per square metre per year.

Electricity generated by PV panels currently costs more than retail power generated by large-scale plants. In addition to the cost of the PV panels themselves, there are additional costs associated with installing the equipment and purchasing equipment to convert the electricity produced from direct current (DC) – used in the home – to the alternating current (AC) used in the grid.

Fully installed rooftop PV systems, which directly compete with retail electricity rates (10 to 25 cents/kWh), currently produce electricity for between 5 and 10 cents per kWh, depending on annual sunshine and orientation of the panels. Adding upfront costs leads to a current full operating cost range of 30 to 80 cents/kWh.

Over the past five years the PV industry has grown at a rate of over 45 per cent a year, largely thanks to policies designed to promote their growth in Japan and Germany. Similar support systems are now in place in many countries, and the industry can expect continued rapid expansion. Growth might accelerate further when costs in the most favorable locations – where there is high sunshine, low interest rates and high retail electricity prices – fall to a level where they become cost-competitive with retail electricity. The opening of unsubsidised markets will lead to further growth and thus further cost reductions along the learning curve, accelerating the deployment and uptake of solar energy in an increasing number of countries. ■

So efficient, cost-effective storage is another key requirement for PV to take off in a big way. Power can be stored in many forms. For example, excess power can be used to pump water from a lower to a higher hydroelectric reservoir, ready to be released to drive hydro turbines at a later time, releasing energy once again. Such schemes are still in their infancy, though.

"A house could use the electricity from its panels to convert water to hydrogen when the sun is shining – and then use the hydrogen in a fuel cell."

An easier option is to store the electricity where it is generated, in a battery. Batteries are bulky and expensive, but every car already has some kind of battery.

"So you could use your car for storage. A photo-voltaic panel charges the battery while the sun shines."

For many years it has been possible to buy a small PV panel that sits on a car dashboard, trickling twelve volts into the car battery through the lighter socket. This keeps the battery topped up against the constant drain from security electronics. An electric car with much bigger batteries would make a far more efficient store for PV power.

The most attractive option, though, is to feed excess domestic and locally produced electricity into the grid and use the grid as a giant virtual battery. The power supply company then gives cash credits – so-called "feed in" tariffs – for power injected into the grid instead of drawn from the grid.

"We will need a smarter grid."

The power supply companies will also need to make grid storage easier to set up and more rewarding financially.

Building design is another part of the PV jigsaw.

"We have so much untapped surface area. PV could become just another aspect of facades. But building orientation is a big factor. Street patterning is a major issue. Hundreds of years of relatively cheap energy have given us street patterns that don't let us orient correctly."

Whether locally generated power is stored on site in batteries or fed back into the grid will depend on the cost and efficiency curves for batteries, and how easy it is for homes and offices to inject power into the grid and get economic benefit. There is not yet a simple DIY kit for homeowners to install, and amateur tinkering with

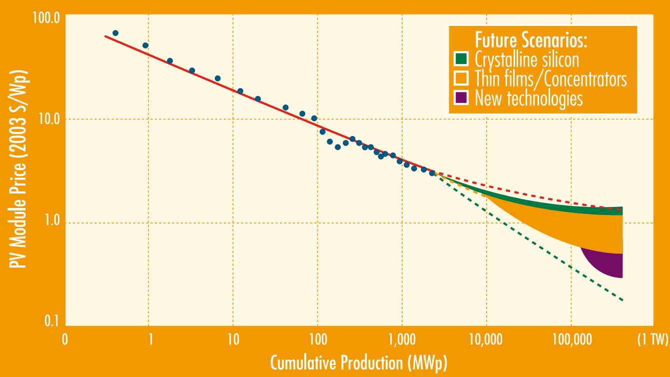
Photovoltaics - First, Second and Third Generation

First-generation PV technology is based on single or multi-crystalline silicon (xSi) with an optically thick single semiconductor junction, where the practical efficiency limit is currently around 20 per cent. This is the classic p-n junction photovoltaic cell where silicon is doped with other elements to make the material preferentially positive (p) or negative (n) with respect to electronic charge carriers. At present first generation PV modules typically cost $4 per watt, mainly due to a supply shortage. Meanwhile manufacturing costs have continued to follow the learning curve (see figure below) leading to very healthy industry margins. A realistic long-term cost target for xSi PV modules is in the order of $1 to 1.5 per watt peak (watt peak: nominal output at peak sunshine for a standardised solar spectrum and intensity).

The second-generation technology, developed to replace the high cost xSi cells, is based on thin film materials – Copper Indium Di-Selenide (CIS), Cadmium Telluride (CdTe) and Amorphous or Micro-Crystalline Silicon (aSi, mSi) thin films are the key technologies – deposited on molybdenum and stainless steel substrates. The efficiency of these modules is only of the order of 6 to 12 per cent. Costs are still close to xSi due to the low production volumes and the relative immaturity of the technology but, given the greatly reduced amount of semi-conductor material, thin film solar cells hold the promise of greatly reduced costs, with a realistic target well below $1 per watt peak.

Third-generation technologies are aiming for either ultra-low costs per m^2 or for very high efficiencies. Both pathways are pursued with the goal to develop cells costing tens of cents per watt peak. The main methods being explored include dye-sensitized cells, organic (polymer-fullerene) cells, and ETA cells (Extremely Thin Absorber). Further third-generation PV concepts are based on quantum dots as a way to increase the part of the solar spectrum that can be captured (e.g. through intermediate bandgaps, hot carrier capture and multiple electron generation). Further on from third-generation technologies, research programmes are focusing on developing advanced multi-junction PV cells from elements of the III/V groups of elements (e.g. GaInP / Ga(In)As / Ge), as currently used in space applications, with the goal of further reducing costs to enable their wider use in terrestrial applications. These highly efficient cells are often used in concentrated solar PV, where mirrors or lenses are used to concentrate solar light onto a small PV cell.

Learning Curve for PV Production



The present learning curve rate is 80% (20% cost reduction for every doubling of cumulative production); projected rates of 90% and 70% are shown for years beyond 2003.

Source: Surek 2005

mains voltages can kill. A safe easy-to-fit kit could be a money-spinner with green credentials.

There are, however, still other constraints that limit the growth of solar energy.

“The biggest practical problem is that the panels don’t work in the dark. So there is no heating at night when it’s cold, which is when you most want it. Storing heat is difficult. Storing electricity is much easier.”

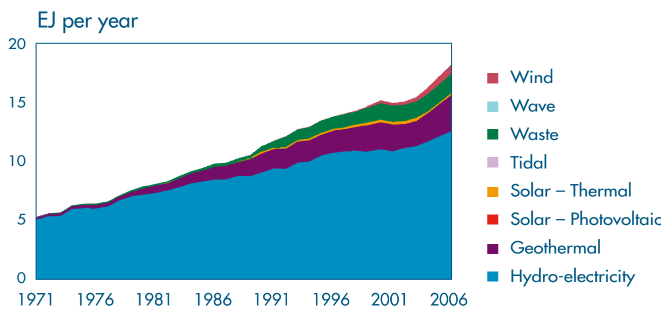
Heating water to produce steam and drive a generator to produce the electricity is clumsy and inefficient, especially for small home-scale installations. PV panels convert light directly into electricity, which can then be used for much more than heating water, and can be stored in a variety of ways. Recent developments in PV technology have made solar power a serious proposition for homeowners.

“When you want to run your lights at night-time you’ll be able to run it off batteries. Will this be the source of the majority of electricity in twenty years? No. But it will be able to contribute significantly to the overall energy mix and also make a significant contribution to reducing greenhouse gases and climate change.”

“Today solar electricity is very expensive but that price continues to come down by about 4 to 5 per cent per year. In expensive electricity markets like Japan, solar electricity is already cost competitive with the retail grid. In California in about ten years it will also be competitive with the retail grid. Eventually solar electricity is going to be competitive with the whole grid, though that’s maybe more a 20 year time horizon.”

“No. I say that advanced photo-voltaics will be competitive with the grid within ten years. Where the curves cross depends mainly on the cost of grid electricity.”

Renewables



Wind Power

As much as 3 per cent of energy from the Sun that hits the earth is converted into wind energy, according to some estimations. This is roughly 100 times more than is converted through photosynthesis into biomass by all the plants on Earth. Wind energy is plentiful, renewable, widely distributed and clean, and reduces toxic atmospheric and greenhouse gas emissions if used to replace electricity made from fossil fuel.

Wind energy is converted into power by wind turbines. The rotation of turbine blades generates electrical current. In windmills, still part of the energy mix in many third-world countries, wind energy is used to turn mechanical machinery to do physical work, such as crushing grain or pumping water.

At the end of 2006, the worldwide capacity of wind-powered generators was 74,223 megawatts – less than 1 per cent of electricity used worldwide. Nevertheless, it is more popular in some places than others and accounts for approximately 20 per cent of electricity use in Denmark, 9 per cent in Spain, and 7 per cent in Germany.

Between 2000 and 2006, wind power generation more than quadrupled. It is used in large-scale wind farms for national electrical grids as well as in small individual turbines for providing electricity to rural residences or grid-isolated locations. The debate continues as to whether to locate wind farms onshore or offshore. The economics of wind power are directly linked to wind speed. Currently, onshore turbines are approximately two megawatts while the largest offshore turbines produce between three and five megawatts. GE (General Electric) predicts that by 2015 this will rise to ten megawatts. And offshore winds are more predictable and stronger than onshore.
However, the capital investment currently needed for offshore wind farms is approximately twice that of onshore installations, and operational costs are three orders of magnitude higher.

Wind and Wave

Building a wind farm with huge propellers near peoples' homes usually triggers a flood of complaints about low frequency noise, interference to TV reception and blotted landscapes. Building the farm in a remote spot, out to sea or in an estuary, involves long cable runs with high electrical resistance and the need for permission to land the cable onshore and connect to the electricity grid. Power is wasted on heating the air, earth or sea.

There are other constraints, too.

"People who like the idea of going green and erecting a wind turbine on their house, forget how much mechanical stress there is on a stormy day. Most houses weren't designed to take the loads. The turbine can weaken or even destroy the building".

A similar host of constraints came up as soon as wave power was discussed. The idea of using waves to power a generator is surprisingly old. In 1901 a British inventor patented a breakwater with a ramp and floating weight on the end of a rope. The waves pushed the weight up the ramp, and as it fell back down the rope turned the wheels of machine.

Modern systems use huge floating metal snake-like tubes, tethered offshore in the open sea. The waves flex the snake, pumping hydraulic fluid to turn the wheels of a generator.

The obvious problem – common to solar power – is the intermittency of supply: on calm days, the snake stops flexing and the generator slows to a halt.

Less obvious challenges exist too: "Wave machines have to be huge. They need vast quantities of concrete, steel and copper which needs energy to make, and transport."

What's more, the power generated has to be carried ashore, by cables.

"And it may be a lot easier to get permission to tether the machine in the sea than it is to get permission to bring the cables ashore across private land".

Moreover, the longer the cables, the more power that is lost through electrical resistance of the copper.

"A lot of your free energy is wasted as heat which warms the water and is lost to the sea".

©Ocean Power Delivery

Wave Power

Wave power refers to the capture of the energy of ocean surface waves to generate electricity. A number of technologies have been considered over the years.
The oscillating water column is the oldest and most successful of these. It comprises a partly submerged structure that is open to the sea below the water surface so that it contains a column of water. Air is trapped above the surface of the water column and as waves enter and exit the collector, the water column moves up and down acting like a piston on the air, pushing it back and forth. The air is channelled through a turbine coupled to a generator and so produces electricity.

A second technology relies on replacing ocean breaks or sea walls with wave collection systems. By creating a series of layered "reservoirs" up a carefully calculated slope, trapping the water from waves and then releasing it through a turbine, the potential wave energy is converted to kinetic energy and electricity. It is estimated that a 500 metre breakwater would have a 150 kilowatt capacity.

A third approach converts the vertical motion of a marine buoy, bobbing up and down in waves, into an electrical charge that is turned into a direct current and sent to shore. It is estimated that a 10 MW station would occupy one and a half hectares of open ocean and a 100 MW station would be cost-competitive with energy produced from fossil fuels.

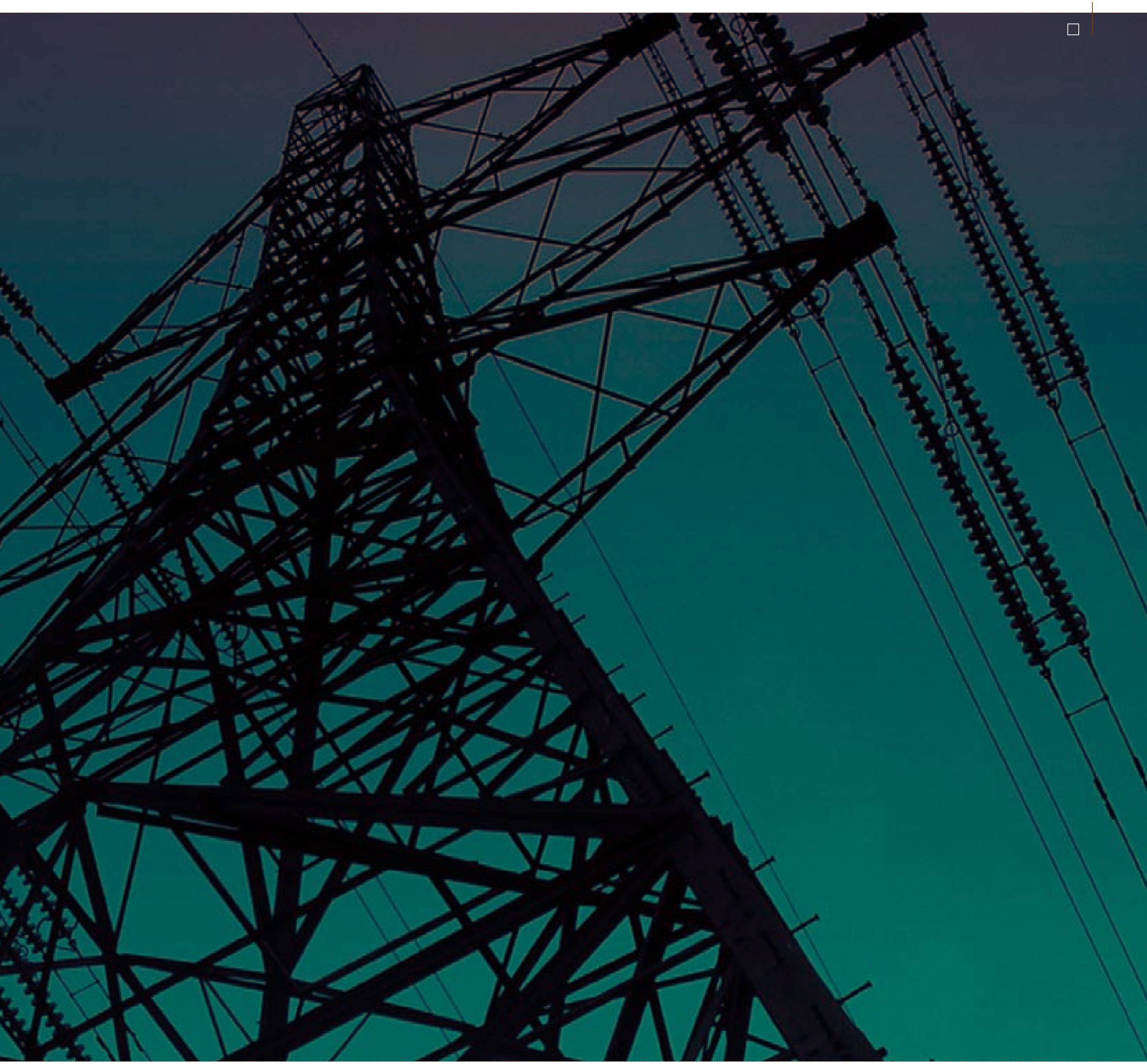
Another buoy system is based on a technology called the Pelamis Wave Energy Converter (the name Pelamis comes from a sea-snake). This system comprises a number of large semi-submerged tubular metal sections. The movement of waves makes these sections ripple or bend, rather like a snake. This bending action forces hydraulic pistons in the device to move – causing fluid to flow inside. This movement is then converted into energy. The machine is the world's first commercial-scale floating wave energy converter. It is estimated that a wind farm occupying a square kilometre of ocean could produce 30 megawatts – sufficient power for 20,000 homes. ■

Technologies

Enabling an Electric World

There is increasing awareness of the link between the use of fossil fuel and global warming. As highlighted in the previous section, technologies that will enable growth in renewable electricity generation are under development. And end-use technologies and applications are becoming increasingly energy efficient.

Nevertheless, the ever-increasing sophistication and range of technologies means that the demand for electricity – for example in transportation – is increasing. How to store and transmit electricity are two critical issues that will have significant implications for energy use and conservation in coming years.



Energy Storage

The first critical issue concerning the development of electricity use is how to store more of it. It's a safe bet that anyone reading this book will be lucky enough to have electricity flowing from a wall socket at the flick of a switch. Someone else is providing power on tap, for anyone to buy, whenever they want it. That someone is a faceless power company, responsible for having enough generating capacity to cope with peak loads – for instance when the weather turns extra hot or cold, and air conditioners or heaters are running full blast.

But soaring electricity bills, brownouts and blackouts in big cities, and increased social awareness are encouraging more people to consider the idea of local power generation. Inevitably, this means thinking about how to store enough power to cover windless days, clouded skies and the hours of darkness.

As one expert put it: "Power and energy are not the same thing. You have to store generated power to create energy for use later." There are plenty of ways to store power, but many of them are not much use for home applications. Water pumping will usually be impractical. Flywheels and capacitors are best suited to vehicles.

We all already use the most convenient power store: batteries. But we use them for storing only small amounts of electricity, to run flashlights, MP3 players and cell phones. The biggest battery most people own is in their car, to start the engine and power parking lights. They are relatively cheap and hold enough power to keep small lights running overnight. But they are also very big and heavy because one of their main components is lead. Smaller and lighter batteries, for camcorders and laptop computers, use lithium and are far more expensive.

Anyone who has purchased an expensive small lithium-ion battery for a portable device will know it's not a cost effective way to store the far greater amount of power from solar panels that would be needed to run a home on dull days or through the night. Lead acid batteries will do the job much better but need a lot of space, and their massive weight means they would need to be stored on the ground floor to avoid the risk of ceiling collapse. Telephone exchanges use lead acid batteries to ensure that subscribers have reliable service during a power failure, but it is not a viable household solution.

So, what advances in battery technology are we likely to see? Moore's Law, named after Gordon Moore who co-founded chip-making giant Intel, predicts that the number of transistors on an integrated circuit doubles every two years – or even every 18 months – with the cost for performance collapsing at the same rate. Moore made his prediction in 1965 and it is still holding true in many areas. Can we expect the same performance and cost improvements from batteries?

"There is no Moore's Law for batteries. The price of cheap commodity batteries declines by 5 or 10 per cent a year. The price of better batteries remains constant but performance improves at the fixed price."

A convenient way to judge storage efficiency is in energy density, measured in watt-hours stored per kilo of weight.

"NiCad (nickel cadmium) gives only 40 watt hours per kilogram. But it is much cheaper than lithium ion. NiCad stores one watt for around one dollar. Lithium ion costs 5 dollars per watt."

“Currently the best lithium batteries give around 200 watt hours per kilogram. Where they are now is probably where they stay.”

“Lithium storage can probably be increased to 400 watt hours per kilogram but people have blown themselves all over the USA trying to make it work. Sony put up the money to make lithium batteries viable. The much publicised problems – self-combusting laptops - were the result of impurities. It’s cobalt oxide that burns. Once burning, it will not stop.”

Lithium-ion Batteries

Lithium-ion batteries can provide significantly more power than other battery technologies. Lithium-ion batteries used in mobile phones and laptops have a capacity of up to 200 watt-hours per kilogram (Wh/kg), compared to 90 Wh/kg for nickel metal hydride batteries (commonly used in hybrid vehicles) and 35 Wh/kg for lead acid batteries such as those used in the majority of cars.

Lithium batteries also have no memory effect, meaning that the way the battery is recharged over time does not impact the battery's performance.

As the most commonly used cathode material (cobalt oxide) is flammable, more stable materials are starting to be used (e.g. iron phosphate based electrodes).

The next generation lithium battery could be a Li-polymer battery, which is lightweight and can be produced in very thin form (ideal for mobile phones). Because they are much lighter, these batteries have a much higher power/weight ratio than current lithium batteries – up to 2800 Wh/kg. ■

Battery Specifications					
	Lead Acid	NiCad	Li-ion	Li-Pol	Super-capacitor
Energy/weight Wh/kg	30-40	40-60	80-160	130-200	3-5
Energy/size Wh/Litre	60-75	50-200	270-370	120-300	4-6
Power/weight Wh/kg	180	150	1800	To 2800	6000
Charge cycle eff. %	70-90	70-90	99	99	97-98
Energy/price Wh/US$	7-18	3.0	3-5	0.3	0.1

Source: Shell estimates

Driving Battery Performance

The mobile phone and computer industries have driven most of the performance progress in small batteries, while the motor industry – in a bid to secure life after petroleum – has driven improvements in heavy-duty batteries.

There were mixed messages on how electric driving will develop. "Within the next 20 years most of us will be driving electric cars not gasoline cars. Electric cars are the most efficient form of personal transportation. More than 80 per cent of the electrical energy you provide ends up driving the wheels. That's so close to perfect that there's no point in trying to improve on that."

"When you design an electric vehicle the first question you ask is 'where is the electricity coming from?' Do we try to generate it onboard or do we store it in a battery?"

"It's perhaps simpler or more efficient to make a pure battery car, but the batteries are expensive. For commuter cars it's priced out of the market – unless the price of fuel reaches 10 dollars a gallon."

"The target range for a car is 200 and 50 miles. The kind of battery you need for that weighs between 500 and 1,000 pounds and costs 40,000 dollars. It can be charged a 1,000 times before efficiency drops to 80 per cent, which is the end of its life."

"A 300 mile battery pack, that lasts 10 years and 200,000 miles, is going to cost 30,000 dollars".

"But if you take out half of the batteries and install a small fuel-burning engine driving a generator, that's a much cheaper system and now the range is essentially unlimited as long as you can refuel it."

“If you have enough energy storage, enough battery, to do a normal day’s commute in the US - for most people that’s less than 40 miles - you can do most of your driving on grid energy and very little of it on burning fuel.”

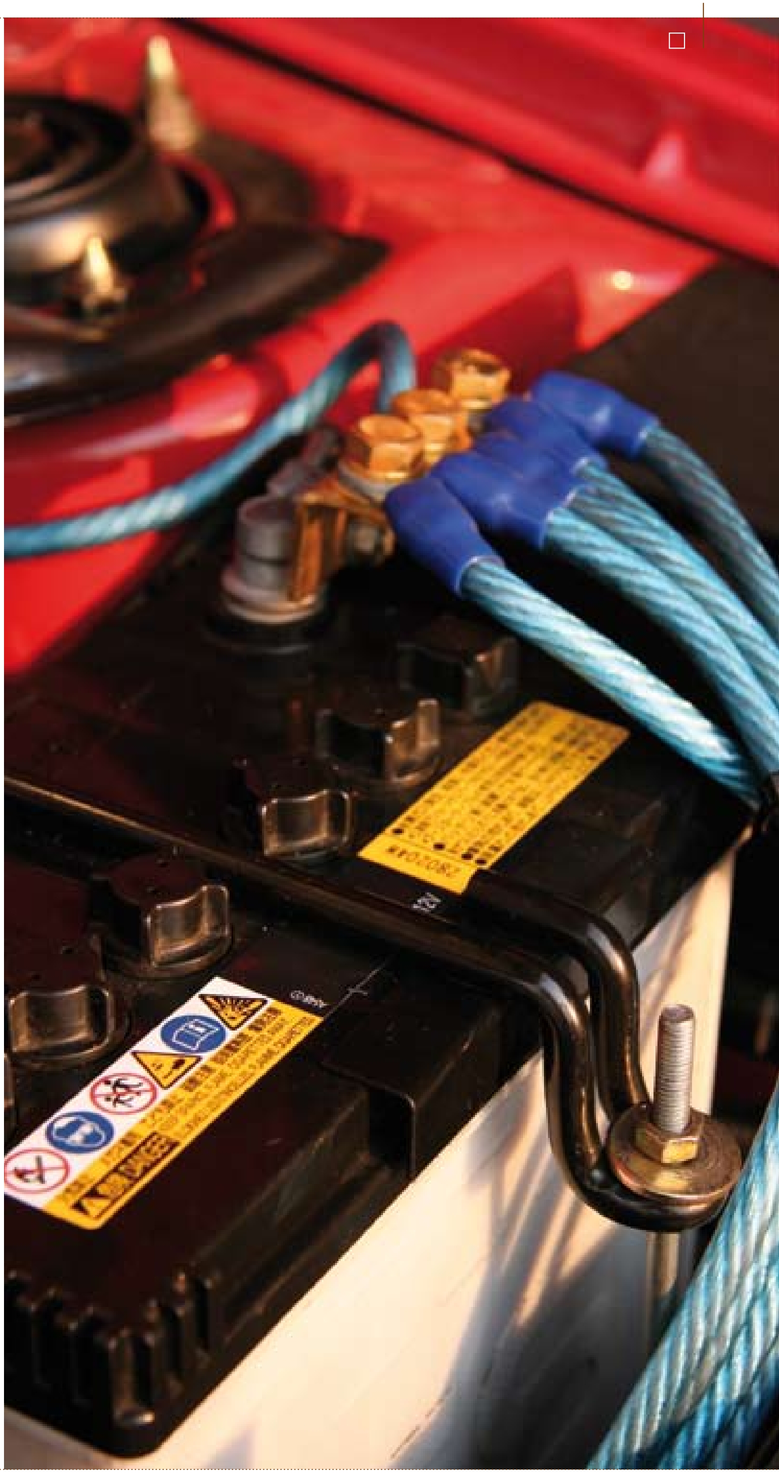
“The trick is to re-design to fit the constraints of what is available. The military had a problem with rifle sights. The batteries went flat. The answer was to re-design the sight to use less power, not look for bigger batteries. We should redesign engines to work within battery limitations and constraints.”

“Someone made a tiny ‘spy fly’, a little flying machine that carried a camera, but then they had to hook it up to a battery to make it fly, and it was then too heavy to fly. You’ve got to plan the power for a device at the design phase.”

“A typical automotive engine is 100 KW and to replace it costs about 2,500 dollars. That’s about 40 dollars a kilowatt, which is very cheap. A fuel cell costs about 3,000 or 4,000 dollars a kilowatt, which is an order of magnitude more expensive. So it will take some clever engineering to get that into a car”.

“But there are an awful lot of times where a huge car has only one person in it. And putting a fuel cell into a scooter is easy. A scooter’s engine is about a kilowatt, so for a hundredth of the cost you solve the value proposition of moving a person.”

“In China the two-stroke is an awful polluter. The government outlawed them at one point and the people just spoke out and said ‘no we have to get around’... The Chinese government couldn’t tell the people they couldn’t have what they need. But if you give them an alternative, a nice clean alternative, you can tell them ‘you don’t use that one, you use this one’, and now you can do what you need to do.”



"Once you get into the situation where you're making these scooters maybe you'll learn the lessons of mass manufacturing and the cost will come down. You can't leapfrog right to the car which has one hundred years of engineering behind it."

The electric car built by Wrightspeed in the USA made a nice colourful example of what can be done now with batteries. The X1 prototype is street legal, packs 236 horsepower and goes from 0 to 60 miles per hour in 3 seconds, and 0 to 100 miles per hour in 6.86 seconds. It beat a Ferrari 360 Spider and Porsche Carrera GT in drag race trials.

"The X1 costs US 150,000 dollars; the only car faster is a US 1.4 million dollar Bugatti. Energy consumption is equivalent to 170 miles per gallon".

"The 25 kwh battery weighs 538 pounds and runs the car for 100 miles. With a 240 volt, 100 amp supply the battery charges in one and a half hours. With a 50 amp supply it takes two and a half hours. With a 110 volt supply it takes 15 hours. Charging is by plug and socket so there is no infrastructure change needed."

Before Kodak went seriously into digital cameras, the company liked to argue that if photography had started out with digital picture-taking, and then someone had invented film, everyone would have said "wow" at the huge amount of detail one 35mm frame can capture. The same may one day be said about electric cars.
"Imagine if we had started out with cars that ran on batteries. Then, after a hundred years somebody suggested changing to gasoline. There would be an outcry over safety issues. In the US there are 750 gas tank fires every day. People have been happy with this for a hundred years."

Hydrogen, Fuel Cells and Hybrids

Hydrogen has long been seen as the super-efficient, super-clean fuel of the future. It can be produced in volume by running electricity through water and can be stored in hydrogen fuel cells. A hydrogen-powered engine emits nothing but pure water. So what role will it play in the future of storing and producing power? "Hydrogen storage is between 1,000 and 3,000 watt hours per kilogram." That compares well with today's batteries.

"If you take a ride from Phoenix to New York City, using your laptop computer, the battery conks out half way through. If you're using a fuel cell of the same size and weight as the battery, it could last four times longer. That means you could go from Phoenix to New York and back again and never have to stop working."

"The hydrogen can be made by using nuclear power to make electricity to electrolyse water, or you can use wind power or solar electrics. So hydrogen is the broker for many other sources of energy."

If it is so convenient and flexible as a broker, and it emits only water when used to power a vehicle, what is holding hydrogen back as a transport fuel?

"Hydrogen is difficult to store and very expensive, though. Storing and distributing it needs an infrastructure change". The cost of switching from today's oil-based distribution and supply system to a hydrogen infrastructure would be astronomical.

"Everyone thought hydrogen was a replacement for oil. That was a hike. It's just for storage. Fuel cells for the home? Only in Japan, where development is driven by subsidies."

Hydrogen Fuel Cells

An alternative way to store energy is as hydrogen. The electrons present in hydrogen can be extracted, whenever needed, by using fuel cells which convert chemical energy into direct current (DC) electricity.

A fuel cell is made up of two electrodes separated by an electrolyte – a substance that conducts electricity. Bipolar plates either side of the electrodes act as current collectors. When hydrogen fuel is added to the cell, along with an oxidant, it reacts with the electrolyte to produce electricity.

A single fuel cell produces little power. To generate usable levels of electricity, several cells must be combined into a stack. Fuel cells have no moving parts and are therefore very reliable as a power source. The by-products of a hydrogen fuel cell are heat and water.

Many different type of fuel cells are under development at the moment, featuring different materials for the electrodes and electrolytes. The most relevant for future practical applications are the Solid Oxide Fuel Cell (SOFC), which runs on natural gas, and the Proton Exchange Membrane (PEM) fuel cell, which runs on hydrogen.

Fuel cells are very efficient – for example hydrogen fuel-cell vehicles with electric motors are 40-60 per cent efficient, compared to just 20 per cent for traditional internal combustion engines.

Cars with hydrogen fuel cells have tanks that store the hydrogen. The fuel cell uses the stored hydrogen to produce electricity, which in turn is directed either to the wheels or stored in batteries.

Some research programmes have developed concept cars that can also serve as mobile power sources with enough power to run a family house. The production of hydrogen requires the use of electricity to extract the gas from water. Hydrogen is only as clean as the power sources used to produce it. ■

Microbial Fuel Cells

Microbial or biological fuel cells use micro-organisms to convert the chemical energy of compounds such as glucose, acetate or waste water into electrons that in turn flow as a current in an electric circuit.
Such cells are still at a very early stage of research. They consist of an anode and cathode separated by a cationic membrane. Micro-organisms at the anode generate electrons and protons to oxidise fuel (such as glucose). The electrons are transferred to the cathode through an external electric circuit, and the protons are transferred to the cathode through the cationic membrane. At the cathode, the electrons and protons are absorbed and combine with oxygen to form water.

In general, there are two types of microbial fuel cell:

- Mediator microbial fuel cells – most microbial cells are electrochemically inactive and use inorganic mediators to generate a flow of electrons. However, most of the mediators available are expensive and toxic.
- Mediator-less microbial fuel cells, in comparison, use electrochemically active bacteria to transfer electrons to the electrode.

Microbial fuel cells have a number of potential uses. Using almost any organic material as a "feed", MFCs could be installed in waste water treatment plants. The bacteria could consume waste material from the water to produce supplementary power for the plant. Alternatively, as an implant in the body, they could take glucose from the blood stream and use this to generate electricity to power small devices such as pacemakers, micro-sensors or micro-actuators.

"Of all the hydrogen technologies the US government is looking at, none is even close to the target. There is not even a pathway to get there."

One idea is to store hydrogen in tiny porous glass beads that can then be pumped like liquid. But hydrogen would still not be a magic bullet.

"Fuel cell hydrogen conversion has an efficiency of around fifty 50 per cent. Electrolysis to make the hydrogen has an efficiency of around 50 per cent, so the total efficiency of converting electricity to hydrogen is 25 per cent." "It sucks for now and it sucks for the future. Nothing comes close to oil."

Nevertheless, as technology in the motor industry develops, our experts were optimistic about the future of hydrogen as a fuel for the transport sector.

"However much charge you can store it is never enough. The answer is a series hybrid."

In a series hybrid, electric motors drive the wheels, with a fuel-burning engine that drives an on-board generator to recharge the batteries. A plug-in hybrid adds the option to plug into a power socket to charge the batteries from the grid.

"Series hybrids with the option to charge from a plug may give the best of all worlds. The attraction of plug-in hybrids is that you can make the battery cheaper." And even these vehicles can be made yet more efficient. For example, most cars waste a significant amount of the energy that they generate. Technology to capture and store that energy is still in its infancy. The Toyota Prius hybrid, for example, only uses a small battery and can't store this generated power. Our experts reckoned more improvements in battery design and storage are on the way.

"In the future, as the cost of batteries goes down and the cost of fuel goes up, the curves cross. Then it's worth considering all-electric cars."

"When will the curves cross? We don't know because we can't predict the oil cost curve. Fuel tax is higher in Europe so the curves may cross earlier there. The future is freedom of fuel choice to generate electrons and then store them."

But the most significant – and achievable – fuel saving across the transport system does not come from cutting-edge technologies.
"Industry is focused on the wrong problem – it's focused on the 35 miles per gallon fleet, not gas guzzlers."

"Cars that do 34 miles per gallon or better – the current efficient cars such as hybrids and small gasoline engine cars – burn only 0.7 per cent of the country's fuel. Almost all the fuel is burnt by the cars at the other end of the scale, the ones that do 10 to 15 miles per gallon. In the US, gas-guzzlers, which do below 20 miles per gallon, consume 84 per cent of fuel. So those are the cars that you need to replace if you want to reduce the national fuel consumption."

"A 29 miles per gallon fleet uses only 4 per cent of the fuel. So you get more reward from moving 10 miles per gallon to 11 miles per gallon than 35 to 50 miles per gallon. There's no impact from improving a 30 miles per gallon fleet to 50 miles per gallon. You save only a small percentage."

"If you replace the 10 miles per gallon car with something that you can plug into the grid, now you're talking serious amounts of fuel saving. If you can get that technology into 10 per cent of the under 20 mile per gallon market in the US, that's a billion gallons a year. Over 10 years those cars percolate through the fleet."

"Research is focused on performance cars to fund it, but the lessons learned apply equally to guzzlers."
"The ideal outcome is biofuel producing electrons for the transportation sector."

The possibility of using ultra- or super-capacitors instead of batteries came up. Capacitors are electronic devices that store energy between a pair of conductors or plates.

"Capacitor storage is between two and ten times better than battery storage and ideal for delivering short drive boosts. A capacitor could store tens of kilowatts."
"Super capacitors support acceleration. A combination of the two, batteries and capacitors, looks hopeful."

"One approach is to use nano-technology; coat the surface of the capacitor plates with tiny hairs to store energy. Storage efficiency then approaches kerosene."
"A venture capital-funded company plans a 500 pound capacitor, with 52 kilo watt hours of storage. If it happens, it would change the world."

This claim attracted some criticism. "It's science fiction, two orders of magnitude better than current technology. Also, it's 500 pounds of dynamite – what happens in a crash?"

Capacitor technology has applications beyond transport.

"There is already a micro-biological battery that uses genetically modified bugs to eat tree sap and charge a capacitor. The capacitor can then shoot off a one second, one-watt pulse into a radio transmitter to send a warning signal from a surveillance network. That opens up all types of interesting opportunities."

Ultracapacitors

A capacitor is an electrical device that can store energy in the electric field between a pair of conductors ("plates"). Charging – the process of storing energy in the capacitor – involves electric charges of equal magnitude, but opposite polarity, building up on each plate. Capacitors are often used in electronic circuits as energy-storage devices.

An ultracapacitor, or supercapacitor, is an electrochemical capacitor that has an unusually high energy density when compared to common capacitors. They are of particular interest in automotive applications for electric (including hybrid electric) vehicles and as supplementary storage for battery electric vehicles.

Ultracapacitors store energy electrostatically as opposed to batteries that store energy chemically. Ultracapacitors can tolerate millions of charge cycles compared to thousands for batteries, with a charge time measured in seconds as opposed to hours. Compared with rechargeable batteries, ultracapacitors have other advantages too. They offer extremely low internal resistance and heat loss, higher efficiency and output power, and improved safety.

Existing ultracapacitors suffer from a number of disadvantages, though. To hold the same charge as normal batteries they have to be bigger. They have a low storage capacity of 5 kw/h – about 40 times less than a similar size lithium ion battery. And crucially, they are a more expensive way to store energy than batteries. They are not, therefore, suited to replace batteries but are useful additions to energy storage systems to provide short power pulses. Doing so exploits the strengths of each system – the power performance of the ultracapacitor with the greater energy storage of a battery.

In vehicles, ultracapacitors can be used together with regenerative braking to greatly improve fuel efficiency under stop-and-go urban driving conditions. Because they can be charged in seconds, ultracapacitors can capture and store large amounts of electrical energy, generated by braking, and release it quickly for re-acceleration.

The storage ability of an ultracapacitor is proportional to the surface area of the electrodes within it. Nanotechnology is the key to increasing this ratio. In 2006 an MIT team began working on a "super battery", using nanotube technology to improve capacitors. They plan to commercialise the prototypes within five years. ■

Battery Constraints

So what is holding us back?

"We could build a battery car that runs for 500 miles but we can't make it cheap. Fuel prices go up and battery prices go down and the curves cross at some point. But in general, batteries don't get cheaper, they just get better. In the USA people are paying 2.50 dollars a gallon for gasoline, which is cheap. So they won't pay premium prices for batteries."

"It's not a question of technology. What you can't do yet is make it cheap."

"One company converted a little van from showroom model to full electric with lithium ion batteries. The van cost under 10,000 dollars; the batteries cost 55,000 dollars."
Batteries are not just expensive, they also degrade. As anyone who owns a camcorder or iPod will know, its rechargeable battery progressively loses the ability to hold charge. Confusingly, different kinds of battery need different treatment.

"The worst thing you can do with a lithium-ion battery is to charge it to one 100 per cent and then let it get hot. Temperature caused by over-charging is the killer. When a battery gets 10 degrees (Celsius) hotter, its life is halved.

"In fact the best thing you can do with a laptop battery is charge it to 50 per cent, then take it out and leave it in a cool drawer. Lithium batteries have no memory so charging to 50 per cent does not damage the battery - as it does with nickel cadmium. But lithium ion batteries do not like being pushed above 85 or 90 per cent. I'd only charge to 100 per cent before a long plane journey. But you shouldn't leave a lithium battery completely flat."

There is an old adage: however much memory or disc storage capacity you have, it is never enough. The same goes for batteries, only more so.

Will we see the most notorious of all gas-guzzlers – Formula One racing cars – go electric with either batteries or capacitors, or a combination of both, instead of an internal combustion engine?

"There is no fun in F1 racing if the cars are electric. There's no roar from the engine - unless you fake it electronically."

Transmission and Superconductivity

The second issue that will have a significant impact upon the development of electricity use is how to transmit it more efficiently.

At present around 5 per cent of electricity produced by power plants is lost during transmission along the miles of cables that supply homes and industry. With energy needs growing rapidly, wasting less power in this way would be one of the simplest ways of meeting new demand and conserving energy resources.
No electrical connection will ever be 100 per cent efficient: losses occur whenever electricity is transmitted. This is usually in the form of heat generated by high-speed collisions between the electrons carrying the current and the metal ions present in the conducting material such as copper cables.

The centralised nature of the current electricity grid – using a small number of large power stations combined with long distribution networks – compounds the problem. Increasing amounts of power are lost the further the electricity travels – first along the relatively efficient long-distance power lines that carry tens of thousands of volts and then as the voltages are reduced for safe use by consumers.

The result is an inefficient system with room for improvement.

Generating power locally, rather than in faraway power plants, would reduce long-distance distribution losses. Economies of scale mean that mini-power stations in the back yard would not be practicable. But "clean" energy sources such as wind turbines or solar generators could work.
"There could be small nuclear generators, but it's not going to happen," assured one pundit. The risks of something going wrong, or criminal abuse are painfully obvious.

Locally produced energy would still need to be stored. Big batteries would work but would be expensive. Far better would be a user-friendly system that would pay distributed power generators to feed power back into the grid.

No matter how it is produced, electricity transmission has far-reaching implications, especially for companies that consume vast amounts of power and the consumers who rely on them. Google requires huge amounts of energy to feed banks of hard discs in server farms that Internet search users depend on around the world.
"That's why the value of a web site can be measured in revenue per megawatt."

Ensuring dependable supplies of power are vital to maintaining seamless and critical operations and are changing the way companies – and in the future individual customers – source and use electricity. Google, and rival search engine giants Yahoo and Microsoft, are now building their server farms near hydroelectric power plants that can sell electricity cheaply.

Although these companies are understandably secretive (there is fierce commercial competition between them and they all share the fear of terrorist attack), our experts had some useful inside information that gave food for thought.

"Google no longer uses commodity PCs, each with its own individual power supply and transformer. Instead Google uses a DC outlet (which allows many computers to be powered from one source) and sends twelve volt DC to all its servers. Houses of the future should have a central converter delivering twelve volts DC. You only need AC to reduce long-distance losses. There are now

more and more DC devices, including lights. Half of all home devices are now DC, and half AC."

Building a central AC-DC converter into the home to reduce the voltage for safe use would involve simple engineering and would waste far less power than the several dozen cheap converters most homes currently use.

Superconducting Motors

Superconducting motors are new types of electric motors that use high-temperature superconductor (HTS) wire in place of conventional copper coils. Because HTS wire can carry significantly larger currents compared with copper wire, these windings are capable of generating much more powerful magnetic fields in a given volume of space. Superconducting motors therefore sharply reduce electrical losses and are far smaller – just one-third the size and weight – of conventional electric motors. This means they can be used in new and innovative ways.

By installing them on the outside of the hulls of ships, for example, they could dramatically lower shipbuilding costs and shorten construction schedules.
A pioneer company in this area, American Superconductor Corporation, recently announced the delivery of a 36.5 megawatt (50,000 horsepower), 75 ton superconductive marine AC motor to the US Navy. In comparison a conventional motor of equivalent power would weigh 250 tons.

Superconductivity

It's a sad fact of life that there are seldom any wave-of-wand solutions to technical problems. But with electric power transmission there is one.

The phenomenon known as superconductivity can drastically reduce the size of electric motors as well as the level of power loss when electricity flows through wires. It's as magic as a Harry Potter spell but until quite recently too difficult and expensive to exploit.

The effect can be, well – electrifying.

"Circuits can run at half a volt instead of 1,000 volts. With a 30-fold increase in current density we can in theory build magnets with hugely powerful fields."

The transition temperatures (the temperature at which superconductivity occurs) rose slowly and consistently with time but in 1986 it went through the roof," an expert on manufacturing superconductor wires and cables, told us. "There was a huge increase in the space of three years. It was truly spectacular and unprecedented. Nothing has happened since, and from our understanding of these materials this is as far as you can go with copper based (cuprate) superconductors."

"In 1988 new materials raised the temperature to 110 Kelvin (minus 163 °C)."

The Holy Grail is a material which superconducts at room temperature.

Superconductivity

Certain materials at extremely low temperatures conduct electricity with zero electrical resistance – making them super-efficient with no power lost as heat. In 1911, a Dutch physicist and Nobel prize winner, Heike Kamelingh Onnes discovered that at 4.2 kelvins (minus 268.95 °C, minus -452.11 °F), mercury has zero electrical resistance. This phenomenon was later called superconductivity.

Research in subsequent decades showed that superconductivity occurs in a large range of materials at ever-higher temperatures. A breakthrough came in 1986 when two scientists at IBM discovered that metal oxide ceramics called perovskites have critical temperatures in excess of 90 kelvins (minus 183.15 °C, minus 297.67 °F). These materials were dubbed "high temperature superconductors" (HTS).

Since then, "cuprate" materials – with layers of copper oxides sandwiched between insulating layers – have been made to superconduct at higher temperatures, of over 133 kelvins, (minus 140.15 °C, minus 220.27 °F). Because these temperatures can be achieved by refrigerators, more commercial applications for superconductivity are now becoming feasible.

Currently, the biggest commercial application of superconductors is in the production of the large volume, stable magnetic fields required for magnetic resonance imaging (MRI), most commonly used in medical scanning technologies. Nevertheless, the commercial use of high-temperature superconductors (HTS) remains limited, largely due to their cost as the brittle ceramics superconductors are expensive to manufacture and difficult to turn into wires. ■

"It's taken a full 15 to 20 years for commercialisation of these materials. But when you use them you can very considerably reduce the size of electrical equipment - by a factor of 5 or 6 so you can put generators on board aircraft. You can put motors underneath ships in the form of pods so they are not occupying space within the ship. Although the motors are actually rather small, they have output powers of 50,000 horsepower, which is rather large. This allows for greater hydrodynamic efficiency. So it will impact on marine applications in the future. The contracts to build these motors are worth millions of dollars."

As so often happens, the military and medicine are driving development.

Superconductors have a myriad of applications. They are used for minesweeping for torpedoes, by mimicking the magnetic signature of a ship. However the main industry for superconducting coils is the medical industry in MRI scanners. This market is worth three billion dollars a year.

Superconductors are also being explored for use in high-speed trains, which "float" above the rails using magnetic levitation to create a frictionless transport system. Shanghai has a shuttle train from the airport, which travels at 430 km/h and the current prototype systems in Japan have achieved 581 km/h.

Manufacturing the materials that enable superconductivity is an exercise in precision.

"We have made superconducting tapes up to 1.5 kilometers in length, supporting around 200 amp. The cross section is about 0.2 millimetres thick. The important thing about high temperature superconductors is that if you get everything right they will support a high current density, millions of amps per square centimeter compared to copper's thousands of amps."

"The boundaries between the layers must be atomically smooth. It takes weeks to manufacture wire through extrusion from billets and then rolling flat to align the grains and annealing."

"The new generation superconductors will be thin film wire, fabricated in an automated continuous reel-to-reel mode. You grow a single long crystal on the substrate – up to 1.5 kilometer long. Fabrication time is reducing from weeks to hours."

"The second generation wire is synthesised at 800 to 900 degrees C and the third generation will be made at just 30 degrees C. We'll just learn how to handle it." There are now many companies worldwide working on next-generation super conductors. In some cases high temperature superconductors are outperforming their low temperature rivals on price and performance. This is because they don't need costly liquid nitrogen cooling, but a local refrigeration unit. "Wind turbines work at low voltage, below 100 volts. And 7 or 8 per cent of the current is lost in the cable run down to the base unit which converts DC to AC. The cables are huge. There is a ton of copper in a 3 megawatt generator."

So local generators like wind farms could soon be using superconducting cables to reduce these losses and replace the copper cables.

"High temperature superconductors will be used for telecoms and computing. And yes, super conductivity is coming to the house and home."

Maglev Trains

Magnetic levitation, or maglev, uses magnetic fields to suspend one object above another with no additional support – defying gravity. Maglev trains use this principle to travel at tremendous speeds because they levitate above the rails, eliminating the friction between the wheels and the rails that slows normal trains.

In order to levitate a train a very strong magnetic field is required. Maglev trains use superconducting magnets (electromagnets using superconducting coils) that are lighter than other magnets. Maglev systems are safe and reliable, have a low environmental impact and require minimum maintenance. One drawback is that because maglev technology is not compatible with conventional rail systems, it requires heavy investment in new infrastructure, limiting its appeal.

Nevertheless, research and development of maglev has been underway at the Japanese Railway Technical Research Institute since 1970. After fundamental tests in the laboratory to verify the feasibility of a high-speed train running at 500 km/h, construction work of a seven kilometre test track began in Miyazaki Prefecture in 1975. The manned two-car vehicle MLU001 registered a speed of 400.8 km/h in 1987. The latest vehicle – MLU002N – has been clocked at 581 km/h. Japanese Railways Central aims to begin a commercial maglev service between Tokyo and Nagoya in 2025. ■

Technologies

Technologies to Change the Game

The industrial revolution witnessed an extraordinary wave of invention and technical innovation. New machines and processes vastly increased efficiency in the production of goods, changing society forever.

The development of computers in recent decades and their ability to process ever greater amounts of data has also triggered dramatic social changes. Historically, the relative cost and size of computers has determined the distribution of computing power. Business, science, the military and education in developed countries have enjoyed the lion's share of these resources. The march of miniaturisation, however, means that increasingly powerful computers are now commonly found in people's pockets in the form of PDAs (personal digital assistants) and cell phones. What's more, developing countries now have the ability to leapfrog other nations straight to state-of-the-art technology, thanks to the widespread availability of cheap, rugged and portable computers and communications systems.

The increased availability of computing power is helping to unlock the door to another world – that of molecular level interactions. Computers are essential tools in the development of game-changing technologies such as nanotechnology – the control and manipulation of matter on the molecular level and the fabrication of molecular sized devices. They are also key in biotechnology – the manipulation of biological organisms, particularly genes, for use in medicine, animal husbandry and agriculture.

It is likely that our developing understanding of what happens at these very smallest levels of life on earth will bring about the next waves of dramatic societal change.
Technology developments in these fields will have profound impacts on our behaviour, how we communicate, travel, consume and how we interact with nature. They will also affect how we produce and use energy. The next two sections examine computing, nanotechnology and biotechnology in more detail.

Data Mining

Data mining uses advanced computer programmes to analyse large information databases to discover patterns and relationships. An ever-increasing amount of data about individuals is stored by organisations and companies – such as medical records, insurance details, financial statements, Internet purchases, travel preferences and online search histories. Data mining is a powerful technique that can reveal insights from this growing mountain of detail that human analysis simply couldn't achieve.

There are essentially two applications for data mining:

- The discovery of previously unknown patterns; data mining tools apply regression techniques to identify previously hidden patterns, for example analysing sales data to explore which products tend to be purchased together, or credit card transactions to create sophisticated consumer preference profiles; and
- The prediction of future behaviour - extrapolation from patterns and trends revealed by data mining can yield predictions, for example of future buying patterns or future sites of credit card fraud.

Data mining is becoming increasingly common in the private and public sectors. Industries such as banking, insurance, medicine and retailing commonly use data mining to reduce costs, enhance research and increase sales. The public sector has used these tools to detect fraud and waste, but is now applying them to performance measurement and management as well.

Date mining is common in homeland security where it is used to identify unusual levels of activities (e.g. money transfers), that might indicate potential illegal acts; and then to identify and track the individuals themselves, such as through travel and immigration records.

Visual data mining is the next wave of data mining technology. It combines traditional data mining techniques with applications that help to visualise data. The combination of automatic analysis methods with human perception and understanding has proved to be very effective in data exploration. Visual data mining techniques have proved to be of high value, especially in exploratory data analysis.

Information Computing Technology (ICT)

Increasingly, ICT is changing how we live, enabling the convergence of technologies and real-time management of masses of data and spawning applications unthought of until recently. Cell phones are now also video cameras, messaging systems and on-line entertainment centres, and will soon be able to replace credit cards. Wi-fi and the Internet mean we can access information anywhere, anytime. Lost in a city and fancy some sushi? Feeling ill and need to find a doctor? Look up a restaurant or find the nearest surgery on your handheld PDA. How much more impact will ICT have on our lifestyles and how will this affect the demand for energy?

"I think there is a world market for maybe five computers."

That's what IBM chairman Thomas J. Watson is rumoured to have said in 1943.

There is no proof that Watson actually did say this, but Greg Papadopoulos, chief technology officer at computer giant Sun Microsystems, recently made a similarly bold prediction. He suggested that a handful of companies would eventually control most of the world's computing power – most likely Google, eBay, Amazon, Microsoft, Yahoo, and some future Chinese giant. This – he believed – will happen because just about everyone and everything in the world will be using local and personal devices that feed off a handful of huge centralised systems.

Our experts quickly got locked into debate about whether these future systems will rely on massive central intelligence feeding instructions to relatively dumb local devices, or smart local devices with enough intelligence to make their own decisions while talking to each other and to a central data store.

Take for example the design of future transport systems.

"Transport is reactive," we were reminded. "Transport technology changes are always driven by other events and developments."

"Europe, the US, Japan, Korea and Singapore are all advanced enough to have high-tech public transportation. The rest of the world is still in the first stage of car ownership; they are going through what London went through a hundred years ago."

"In North America there were just 144 miles of paved roads a hundred years ago. Now look at what we've got. More people now have the opportunity to own a car for the first time."

The increasing use of cars for personal transport has led to the development of initiatives to impose restrictions on how vehicles are used in large cities.

"In London and Singapore traffic control is by pricing. London only got congestion charging because the Mayor, Ken Livingstone, was a maverick who pushed it through. The congestion charge works on the principle of drivers being rewarded by not being given a penalty."

So how will ICT transform the way we get around and what impact might that have on energy needs and consumption?

"The next step could be driverless, autonomous cars that talk to each other; smart devices rather than smart people."

©NASA-JPL-Caltech

Autonomous Vehicles

A fully autonomous "driverless" vehicle would free up passengers to work, communicate with others or simply sit back and enjoy the ride. Building such "intelligent" vehicles is a hugely complex challenge, requiring enormous amounts of computing power to keep track of the rapidly changing conditions on our roads. Doing so involves:

- Sensing obstacles and how to get round them;
- Navigating between locations;
- Moving, steering, and avoiding collisions while observing road rules; and
- Controlling the vehicle by accelerating and braking.

The Mars Rovers – small robotic vehicles deployed by NASA for exploring the planet Mars – are successful examples of autonomous vehicles. For earth-bound road transportation, autonomous vehicles achieved a milestone in 1995 when a car drove from Munich to Copenhagen and back under computer control 95 per cent of the time.

A number of technologies that could enable autonomous vehicles are already available in standard cars. Driverless parking has been available in some cars since 2006. The system uses cameras and an array of sonar sensors to automatically parallel park the car without assistance from the driver. Many luxury cars, along with commercial trucks, have lane departure warning systems as standard. These alert the driver when the vehicle is leaving a lane without indicating. Already in development is the next generation of the technology that applies corrective steering to guide the car back inside the lane. There is also radar-assisted cruise control, which keeps cars at a certain speed but adjusts this according to obstacles ahead.

In 2005 the DARPA (Defence Advanced Research Projects Agency) Grand Challenge in the U.S.A. provided an opportunity to witness a demonstration of the latest driverless vehicles. Completely computer controlled, with no people travelling in them, the vehicles undertook a 200 km (124 miles) off-road course complete with rocks, switchbacks, tunnels and narrow roads. Though many failed to complete the course, it provided insight into the challenges faced in perfecting this technology. Similar demonstrations have been carried out in urban environments with road rules, traffic regulations and dynamic obstacles such as other moving vehicles.

"Yes, but when I own a car, I want to drive it. Young people play computer-driving games so they will want to control a car. Truck drivers don't feel the same way, though. So trucks could be the first vehicles to become driverless. Automation is most likely to start with long-distance cargo between stations. Consumer use will come in much later, at the end."

"Autonomous cars don't give performance car pleasure. So we shall see new and different status symbols. It won't be the engine, but gold-plated windows or whatever."

"One question is whether driverless trucks will use existing roads or dedicated roads. Embedded sensors can be retrofitted to existing roads. The sensors can be at the side of the road."

All through the seminar in Bangalore there was a continuous background chorus of car, scooter, truck and bus horns. This prompted a thought:

"Artificial vision is the biggest challenge. Today every horn honk means - do you see me? But how will robotic vehicles do this?" "Autonomous vehicles will communicate with other autonomous vehicles. ID card sensors in the vehicles will say 'Don't hit me'."

"If you take the idea of automated vehicles further, drivers could pay a subscription to get the best route – perhaps paying extra to route others out of their way, with coffee stops advertised to buffer traffic."

We shall be driving ourselves for a long time yet, though. There are both technical and commercial obstacles to automation. The lead-time for a car manufacturer to make major design changes is between seven and ten years. It takes at least double that time to make major changes to infrastructure to enable new systems.

"It's relatively easy to get automated cars to go from A to B. The difficulty is when a lot of cars are going from many different points A to many different points B. Planes can fly themselves – but they can't move themselves around on the ground."

"And we are talking about tens of thousands of cars. They can't all have their own lanes."

"A central computer controlling all the cars knows where every car is. This would be more a reliable system. But who will own the system? Will it be the Government or will it be a free market venture?"

"I'd say that in practice centralised control is just not viable. If the car is moving at 120 km per hour the round-trip time for the control signals is just too long to prevent accidents."

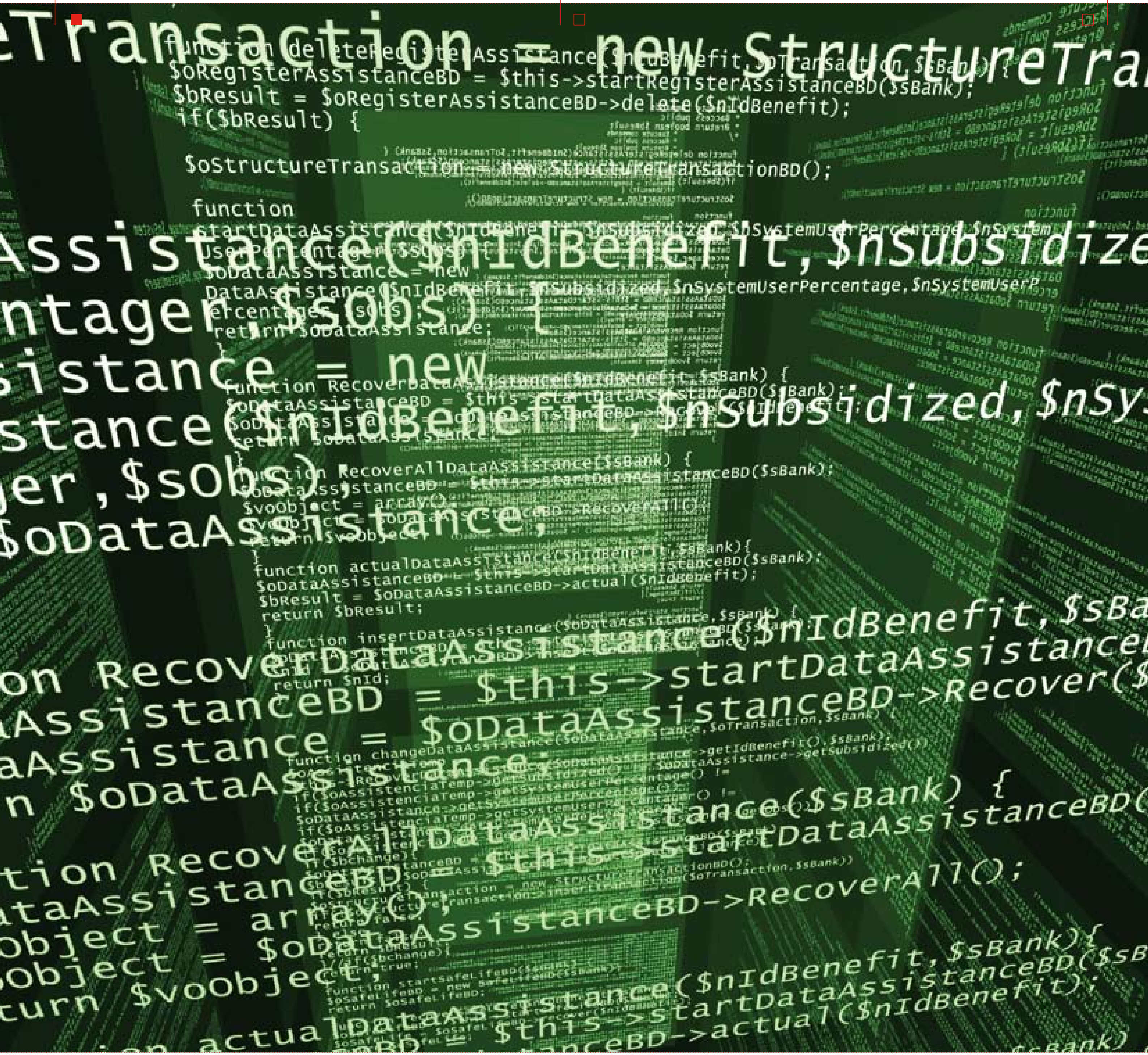
"The downside is that these systems may consume more power than traditional driving. And automated routing systems are very vulnerable. If I were a terrorist I'd know where to put my bomb to bring the whole system to a halt."

"They will be easier targets for electromagnetic pulse weapons, as well".

"Any system has to be designed for local and remote failure. Perhaps the answer here is a hybrid system, part local control, part central."

"One idea might be to use bus lanes for autonomous cars. If you are sitting in a traffic jam and you see an autonomous car going past, you may well change your view about wanting to drive yourself."

"So we could see road trains with dedicated lanes – swarm robotics."



This prompted some thoughts on how robotics will develop.

“In the movies there are terminator robots and robots that save the world. In the next 20 years we’re going to see more systems where humans or animals work with robots or machines, for instance for disaster response in situations where it’s too dangerous for humans. You can use sensing technology and dogs, with robots getting into places that are more dangerous. We’ll see a lot of systems where the human is not being replaced, but enhanced by robots.”

Robot vehicles are, of course, already used for bomb disposal but a human “driver” remotely controls them.
Completely autonomous vehicles do already exist. But they are literally out of this world. One of their designers explained:

“The mission to put a rover vehicle on Mars was a new case of necessity driving innovation. The vehicle had to be solar powered and very light. The rover uses stereo vision to look ahead over the terrain, make judgments on the best and safest route to take and then drives blind until the next set of readings are taken.”

All these developments rely of course on computer control. Did our experts agree with the views of Greg Papadopoulos?

The balance of power in the computing world can change very fast. The last 20 years have shown how famous names in software and hardware can quickly disappear without trace, often leaving stored data inaccessible to the owner. There is currently a power struggle between the proprietary closed computer systems, notably Apple’s

Quantum Computing

First proposed in the 1970s, quantum computing uses the principles of quantum physics – the study of the relationship between energy and matter – to make vastly faster and larger calculations than conventional computers are able to do.

Traditional processors and memory chips encode information into binary numbers, either a zero or one. They can only do calculations on one set of information at a time. Quantum computing processors and memory chips, on the other hand, use atoms working together in combinations that are known as qubits. They encode information as a series of states, such as the spin directions of electrons or the polarisation orientations of a photon.

The states of these atoms, known as their quantum mechanical state, in turn might represent a 1 or a 0, a combination of the two or a number expressing something between 1 and 0.

A quantum computer can perform calculations on many numbers simultaneously, unlike a binary system. This means a quantum computer can be much more powerful than a traditional computer and perform myriad operations in parallel.
Quantum computing is not well suited for tasks such as word processing and email, but it is ideal for tasks such as cryptography, modelling and indexing very large databases ■

OSX and Microsoft's Windows, and open source software such as Linux. Apple and Microsoft dominate now, but there could be a very different situation in five years' time. The open source movement is gaining momentum. It already provides a free alternative to Microsoft's expensive Office software for Windows.

"Some people want to have control of what their computers are doing. Alpha geeks call it 'scratching one's itch' – developing software or tinkering with early stage technology. The open source movement relies on this."

"If you can't open it, you don't own it, they say."

"Engineers want the right to tinker, to reverse engineer and learn how to make things better."

Although the world now depends on computers, as anyone who uses them knows only too well, the whole field is still very immature.

Sooner or later every computer crashes and gives obscure error messages, or asks questions the average user has no hope of answering.

"What we need is self-healing software that will detect its own faults and repair them without the need to go on a caller helpline. It tells you what's wrong and fixes it."

"Windows Update works like this. It is an intelligent agent. It goes out and tells Microsoft what you've got and comes back saying, 'Here's what you need'. But it only works if the network works."

However, it was pointed out that not all intelligent agent developments have been welcomed. Early versions of Microsoft Office once had an animated character – called the 'paper clip' – that was designed to put a welcoming face onto complex software. Not everyone welcomed it – most were so annoyed by it that they turned the application off.

Designing the next generation of software that goes beyond unexpected error messages is problematic.

"The state of software was grim 20 years ago, and it's grim today. Half of all software projects fail. We have learned nothing since the 1960s. Look at the delays in launching Vista."

This led to discussion about some of the downsides of an increasing reliance on computing technology.

"For Internet purchases, anything more than one click is one click too many. With online sales once you get past three clicks the sales level falls off. Identity management is the solution. The system has to know who you are."

"That needs foolproof software and as a software writer I can tell you that foolproof software is not foolproof."

"And as we rely more on network control we put ourselves at greater risk. Someone can hack into my refrigerator and make all my food go rotten. I can see a car virus coming up…."

Despite these risks and challenges, life without computers is no longer an option.

"It's safe to say that the human brain no longer has the capacity to handle all the data thrown at it, and currently there is not enough computing power to process all the data coming from the Hubble telescope."

New approaches to constructing computers – and the software that runs on them – have the potential to yield vast increases in the speed of processing data. However, this field is still in its infancy as engineers grapple with novel approaches to overcoming traditional barriers.

“Moore’s Law has stopped working. You now just put more CPUs (central processing unit – the component that executes programmes) in a box. Google uses off-the-shelf 1GHz PCs, 100,000 of them, instead of building a super computer.”

“But if the programs aren’t written to cope with multiple CPUs, the box will run no faster.”

Computers and increasingly sophisticated software also waste their processing power, memory and storage capacity on features which few people use and cosmetic graphics. The next major development, we learned, could well be a return to basic essentials.

A non-profit organisation, proposed by Nicholas Negroponte of MIT, is working to develop a stripped down, bare essentials Linux laptop computer for 100 US dollars. Known as the One Laptop Per Child (OLPC) project, the team hopes to bring education to those – particularly those in developing countries - who cannot afford books.

No one disputed that OLPCs can bridge the digital divide, and bring education to the under-privileged. But in the real world there are always two sides to every coin. There could be a huge black market in OLPCs, with the under-privileged selling them to get money for food and medicine. ■

Self-Replicating Machines

A self-replicating machine is a man-made structure able to make a copy of itself autonomously, using simpler components or raw materials taken from its environment, without any human intervention. If research into their development proves successful, they could lead to dramatic efficiencies and savings for a range of applications. In essence, the initial investment required to construct the first self-replicating device would have an infinitely large payoff with no additional labour cost.

NASA has been investigating self-reproducing machines on the surface of the moon to make solar cells that could be cheaply transported to vast solar-power satellites that would beam solar energy back to earth. Researchers estimate that a conventional factory would cost about $1 billion and would take about 6,000 years to perform this task. A self-replicating factory of the same initial size and cost, on the other hand, could do the job in just 20 years, because it would make not only solar cells but also more solar-cell factories.

Another area where robotics will advance over the next few years is at the nanometer level where nanobots will be the next generation of nanomachines. Advanced nanobots will be able to sense and adapt to environmental stimuli such as heat, light and sounds; conduct molecular assembly; and, to some extent, repair or even replicate themselves. ■

Efficiency

Impacts

Previous sections of this book discussed specific energy resources and technologies. Now we turn to how various combinations of technologies could be adopted by society to change the way we live and how we consume energy and manage environmental impacts such as greenhouse gas emissions.

The first part in this section explores how to make better use of existing technology to bring about increased efficiencies in energy use. It looks at the technology that enables this, and also at regulatory intervention to introduce stricter efficiency standards and incentives to change behaviour.

The Distributed and Connected section looks at how technology is changing the way we communicate, do business and interact. These changes in turn have direct impacts on other complex systems including transportation. This is one sector that has been an early adopter of technologies such as global satellite positioning (GPS) that are now finding their way into many aspects of society. GPS, for example, now enables many cargo shipments to be followed around the world from any computer.

The Track and Trace section discusses how tracking technology impacts a range of sectors. This technology offers substantial benefits for global trade, but can also produce unintended consequences if it falls into the wrong hands.

Finally no discussion of impacts would be complete without examining the other liquid that the world depends on: water. The very real prospect of severe water shortages is driving significant developments in areas like desalination. Closely connected to water is the issue of health, and the Water and Health section explores these topics.

Better Use of What We've Got

The continuing population growth and industrialisation of developing countries is driving an accelerating consumer demand for goods and services. Meeting this demand requires the consumption of a finite supply of raw materials. The ability of the planet to absorb the impact of human activity is being tested.

One thing is clear – the current rate of growth is unsustainable. We only have one planet. We are therefore faced with a choice. We either reduce human activity, or do "more for less" by improving the efficiency of use of all inputs and reducing waste. Our expert discussions focused on how we could maintain levels of activity more efficiently, recognising that success will require both the application of technological solutions and changes in behaviour. It was clear that this in turn will only happen if governments and regulators introduce stricter efficiency standards and incentives.

"Can the world's resources support all of Man's current activity? Probably not."

"There's a school of thought that says so much carbon is being emitted and world growth is so fast that you can't stop it going up considerably. So if all the negative thoughts about global warming are true, you can't do anything about it. So you might as well just have a big party."

Fortunately, not everyone thinks this way. From governments down and from lobby groups up, there is a will to stop environmental plunder. The obvious first step is to make better use of available energy resources, and to stop wasting what we've got. A wide range of experiences and ideas were bounced round the discussion rooms. They fell into several categories:

Manufacturing

Heavy manufacturing was identified as one area where small increases in efficiencies can yield large impacts. Steel mills in particular came under scrutiny for two reasons: the predicted massive increase in production needed to satisfy global demand, and the potential savings that new technology can offer.

"Over the last few years, the world's steel production has been going up 6 percent per year, mainly driven by growth in demand from China."

"At least one-tenth of the world's CO_2 production comes from blast furnaces and the cement industry."

"But digital control technology now lets manufacturers specify the thickness of the steel. We are seeing new applications for steel in the building industry, mainly to make it look nice. Previously only a few thicknesses were permitted. This kind of control technology could have a huge impact, with less waste."

Recyling materials is one way to use existing resources more far more efficiently.

"A lot of steel is recycled. It's the best example of things for which an efficient recycling system really does work. There is currently not enough scrap steel in the world."

The primary production of crude steel uses about three times as much energy as recycling scrap steel. However, the growth of steel production over recent years has been concentrated in China, a country without scrap reserves.

"Wood and cellulose are easy to disassemble. Composites are lighter but if you glue composites together you can't disassemble them. The only thing you can do is put the material in landfill and wait 100 years. You can't recycle them. There has been more impetus behind creating composites than taking them apart. What are needed are selective solvents. It's just a technology problem."

Buildings

While developing new technologies can solve some problems, there are also valuable lessons in efficiency to be learned from history. A prime example is how to design a house to prevent the sun from turning it into a hothouse, which then costs energy to cool.

"Building orientation and location can make a 50 per cent difference to energy consumption. We have forgotten classic building knowledge that people used a thousand years ago because they had no air conditioning or heaters. The limiting factor now is often street patterns. Hundreds of years of relatively cheap energy have given us street patterns that don't let us orient buildings correctly."

"Taxis in Hong Kong have two roofs for insulation so they don't heat up while standing still. The Chinese did the same thing two 2,000 years ago, with homes with double-layered roofs."

"One day someone in Houston Texas will all of a sudden discover something that's called the 'awning' – a new way to keep heat out of the building. They'll think 'wow what an incredible innovation to stop the sun's heat before it gets trapped inside a glass box' – even though we've known how to do that for hundreds if not thousands of years, with people in the south west of the United States of America building their homes with awnings of rock."

"We will rediscover the fact that keeping heat out makes more sense than trying to change it to cool inside the building. Low energy housing is widely adopted in Germany and Scandinavia, but not elsewhere."

"As well as awnings, there are shutters. Those will come back too. Window shutters are common in Switzerland and Germany."

Cities

Although cities cover less than one per cent of the earth's surface, they hold more than 50 per cent of the world's population, consume 75 per cent of the world's energy and are responsible for 80 per cent of greenhouse gas emissions.

Perhaps the challenge is to learn how to live in cities and re-design the built environment?

"This year, 2007, is the year in which we have become urbanised," an architect told us. "There are more people living in cities now than in the countryside and that trend will continue. Over the next twenty years we'll see cities growing on an unprecedented scale in the developing nations."

"India has Special Economic Zones; satellite towns that are 50 km to 100 km away from the main city centres. The SEZs are self-sufficient integrated cities with commercial businesses and residential buildings, with hospitals and schools and mass transport infrastructure. We could have something like SEZs all over the world."

New towns offer considerable potential to improve energy efficiency. Building environmental and energy considerations into new developments is easier than trying to redesign and retrofit existing urban centres. China may provide the blueprint for the next generation of energy-efficient cities.

"Dongtang is on an island next to Shanghai, in the Yangtze river delta. The site is three-quarters the size of Manhattan. It's an area with huge ecological sensitivity, next to a wetland on a waterfowl migratory path. The Chinese government and the developer have a goal for this completely new city: to achieve close to zero carbon

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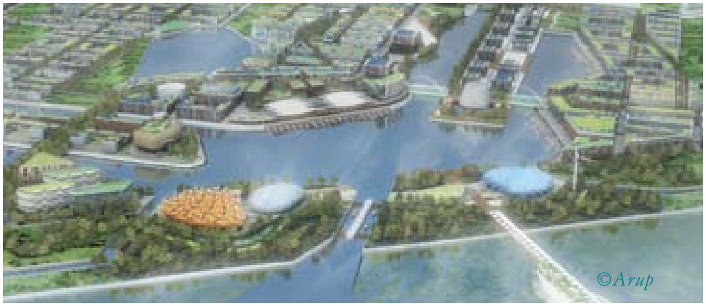

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Dongtan Eco-City

Dongtan is a sustainable eco-city under construction just north of Shanghai on the third largest island in China. Designed by the engineering and business consultancy Arup, the city will use renewable energy, water purification and re-use, combined heat and power systems, and low-energy housing. It will be as close to carbon neutral as possible.

The completion of the first phase of Dongtan is scheduled for 2010, with road and rail links to Shanghai and local airports. By 2050 it is expected that the city will house half a million people.

The city – which also features extensive planning for social, cultural and community developments – will provide a model for other cities around the country that Arup is designing. ■

emissions, with energy and material recycling, sewage capture to fertilise farmland, wind and wave turbines and strict energy conservation rules for the citizens."

Despite having the advantage of starting with a clean slate that allows the use of "best-of-breed" efficient technologies, challenges remain.

"Even when we build completely new cities on green-field sites, as is happening in China, it remains impossible to get individuals' carbon footprints down to the target level."

"It has proved hard to do. In fact it's shown that we are not yet able to design a city that's good enough, even on a green-field site. We now know there's no perfect system. But we have to start somewhere."

"Wherever buildings are built, a lot of energy is used, from manufacturing the materials right through to construction. This 'embedded energy' is a one-off hit but the building structure then continually consumes energy to run. The challenge is to keep the embedded energy and running energy as low as possible."

"Different materials have different levels of embedded energy – cement having the highest. We need to use materials with lower embedded energy."

We were reminded that concrete is sometimes shipped by air in China – "if you are building something that needs to be finished in a hurry, concrete becomes a high value good"– which increases the level of embedded energy and the cost.

Vehicles

From stationary buildings, the conversation moved on to how to build more efficient vehicles for mobility. Previous sessions had made clear that our experts doubted any significant move towards automated road travel would occur within 20 years. So what can be done to improve existing transport systems?

"Frankly it's very difficult to see how the developing world can get the transportation it needs while also respecting the needs of the environment."

"Today's transportation is almost 100 per cent dependent upon petroleum. Right now the only thing you can use as an energy source for personal transportation is oil. Physical infrastructure is slow to change. A building will last for 50 years; a road will last for 20 years. Usually you can't widen roads, you can only build more levels. And typically a vehicle lasts 5 to 10 years, or even 20 years."

"Vehicle technology will be completely modified during those years."

"You come back to the fact that electricity is the universal interchange mechanism. The grid already exists. You can generate electricity from any kind of fuel; from solar or from wind or geothermal or nuclear or hydroelectric, and send it out over the grid and the car can use it. So it doesn't have to depend on oil."

The biggest potential efficiency gains in transportation, however, may require a change in the current paradigm. The approach to a better system may lay in a total re-examination of some of the central tenets of the way people view their vehicles.

“We need radical re-thinks. Rather than transporting a 3,000 pound car to carry a 200 pound person we should focus on how we get that 200 pound person around. Eighty per cent of car fuel is used for engine tick-over, only 20 per cent to move the vehicle.”

“Yes, one thing we can do is to stop moving air. The car is a big heavy box full of air”.

“How many times do you get in the car and not need all its space? It would be so much better to use just what you need, just the seats and engine. You don’t need the boot or trunk. A modular car, like automotive Lego, could be configured to suit what you need.”

“With automotive Lego you don’t buy a car, you buy a transport solution. Maybe it floats on an air cushion instead of wheels. Maybe it’s inflatable to change the size. Or maybe the more practical solution is just to have two cars and use whichever one is best for the day’s job. Perhaps we’ll buy a ‘ticket to drive’ which will become a tradable commodity, just as some people already sell parking rights they do not use.”

"Or perhaps we just belong to a pool of cars and borrow what's needed."

Perhaps the most publicised recent attempt to change the way people view personal transportation was the development of the Segway. A two-wheeled electric device, the Segway resembled an old "push mower" that was used to cut lawns. It relied on a complex set of motors driven by a gyroscope to prevent people from falling off while moving. Although the Segway failed to reach mass adoption, our group of experts saw it as a potential step in the right direction.

"Why did the Segway fail? Because it made people look silly. But things may be different in 20 years' time."

So how easy will it be in practice to introduce this kind of new thinking? The difficulty in developing new directions for transportation is the number of people that have a vested interest in the outcome. Unlike the power generation industry – where there may be several thousand companies to negotiate with – in transportation there are hundreds of millions of users.

Government intervention can be the key, and a charismatic leader – such as "Governator" Arnold Schwarzenegger – can make a huge difference.

"After years of being famous for smog, the state of California is at the leading edge in terms of emissions from cars and so is actually driving the industry across the country and maybe across the world."

Segway PT

Like a gadget from Star Trek, the Segway Personal Transporter is a futuristic two-wheeled device able to balance on its own, allowing users to stand upright and zip around safely.
When humans lean forward, the brain recognises when the body is about to lose balance and triggers an impulse to put a leg forward to prevent falling over. If the leaning forward continues, the brain will keep putting the legs forward to keep the body upright. Instead of falling, the body walks forward, one step at a time.

The Segway PT does very much the same thing, except it has two wheels instead of legs, a motor instead of muscles, a collection of microprocessors instead of a brain and a set of sophisticated tilt sensors and gyroscopic sensors instead of the brain's inner-ear balancing system. Like the brain, the Segway knows when it is leaning forward. To maintain balance, it turns its wheels at just the right speed, to remain upright. This is called dynamic stabilisation.

An intelligent network of sensors, mechanical assemblies and propulsion and control systems control the Segway PT. The second a person steps on the machine, five micro-machined gyroscopic sensors and two accelerometers sense the changing terrain and the body position at 100 times per second – faster than the human brain can think. ■

"Status could be a driver for good. People are proud to own a hybrid car. It's like bragging."

"SUVs, Sports Utility Vehicles, became unfashionable in US when the price of gas passed three dollars a gallon. That was the tipping point."

"Right now the United States is the dominant car market, but America's not going to be the dominant market for very long. China's going to take that over. India's coming up strong. And as people have more money, they want to buy cars, they want to drive. That's just the way it is."

"As the economy develops, people have more money, their economic threshold of pain increases. It is getting harder to make it uneconomic to travel."

The idea of automated travel came up again. It's an idea that just won't go away, however many technical obstacles there are.

An expert with close connections to the military argued:

"Army tanks already give the driver a chance to stay safe inside and rely on cameras and radar outside. Why not a car? And if the car can talk to other cars and drive itself, the driver needs no windows. There could be a virtual reality display with synthetic noise for background while the driver reads a book or plays a game."

"Or perhaps virtual travel may one day reduce physical travel," someone countered. "You could watch a holiday on your wallpaper instead of flying to the destination. Now that would save even more fuel."

Air and Rail Travel

Although the price of road vehicle fuel continually increases, the cost of air travel remains surprisingly low.

"There have been no physical, technical or economical constraints on air travel growth. It is growing 5 per cent year on year."

"Right now planes fly on roads through the air from Point A to Point B. Planes can't just go wherever they want. What if you could go from anywhere to anywhere? Airlines could then be flexible. Of course there would be regulatory and infrastructure issues. There would have to be no-fly zones over military areas and there would be perceived safety issues. But flexible flying would give big fuel savings."

While new business models may lead to increased energy efficiencies, big fuel savings are also the drivers behind the deployment of new technologies in commercial aircraft.

"The new Boeing 787 uses new technologies, such as composites, which reduce the aircraft weight to claim a 20 per cent performance improvement. Flying from Los Angeles to Hong Kong saves 20 per cent on the fuel burnt."

Boeing expects the airline market will need about 2,900 new aircraft over the next 20 years, and the lean-burning 787 will fit the bill. One fear our experts expressed was that this means flying could become even less expensive so there could be an overall increase in carbon emissions. The airlines will need to think hard about how to respond to critics.

Composites in Airplanes

In composite materials, resins and high-strength fibres of glass, boron, carbon or graphite are blended to produce lighter, stronger, and more corrosion and fatigue resistant materials than traditional metal alloys. They are commonly used in the construction of modern aircraft and, increasingly, in high-end sporting equipment such as bicycle frames and performance cars.

Composite materials are expensive, and their use in the military drove their early development. The B2 Stealth bomber was one of the first aircraft to extensively use composites. In 2005 Raytheon launched a business jet with a carbon fibre/epoxy honeycomb fuselage. Automated fibre placement machines place every strip of carbon in exact position to achieve maximum strength with minimum weight. Construction takes about one week, which is considerably faster and more efficient than the traditional process.

Boeing has used composites in commercial aircraft for many years, with the tail of the 777 being completely composite. However, with the development of the 787, the company is the first to launch a full-size commercial airliner in which almost half the aircraft – including the fuselage and wings – will be made of composites. By manufacturing a one-piece composite fuselage section, the company eliminates one and a half thousand aluminium sheets and around 40,000 fasteners.

"OK then. How about an airline that only flies thin people – or charges lower fares because there is less weight to transport and so less fuel used?"

Will heightened security and airport delays act as a brake?

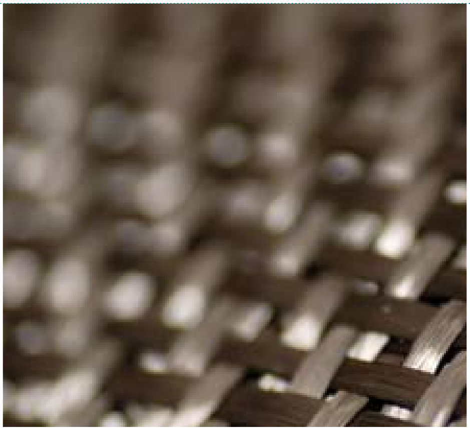
"Train travel is taking business away from the airlines. It's more relaxed, with fewer security problems. It's easier to travel to Paris by train than fly. But what happens when the first Channel tunnel train is blown up?"

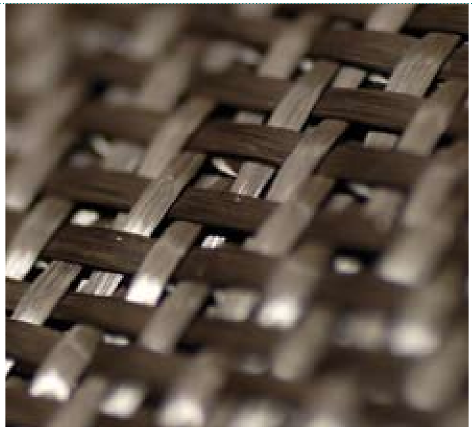
"Rail will attract terrorists. It could all change very quickly. Look at the Madrid bombings."

"Rail security will catch up and the airlines will find new ways to get passengers through airports more quickly. With radio-frequency identification (RFID) and iris scans, people will be able to run through to planes again".

"It may make sense to invest more in police intelligence than security checks."

"Security could rely on personal data transfer – your data describing you travels electronically. Mobility butler software tells you the best way to get somewhere from any starting point, by road, rail or train. Then you have the option to travel in ways that make security searching much easier and quicker."



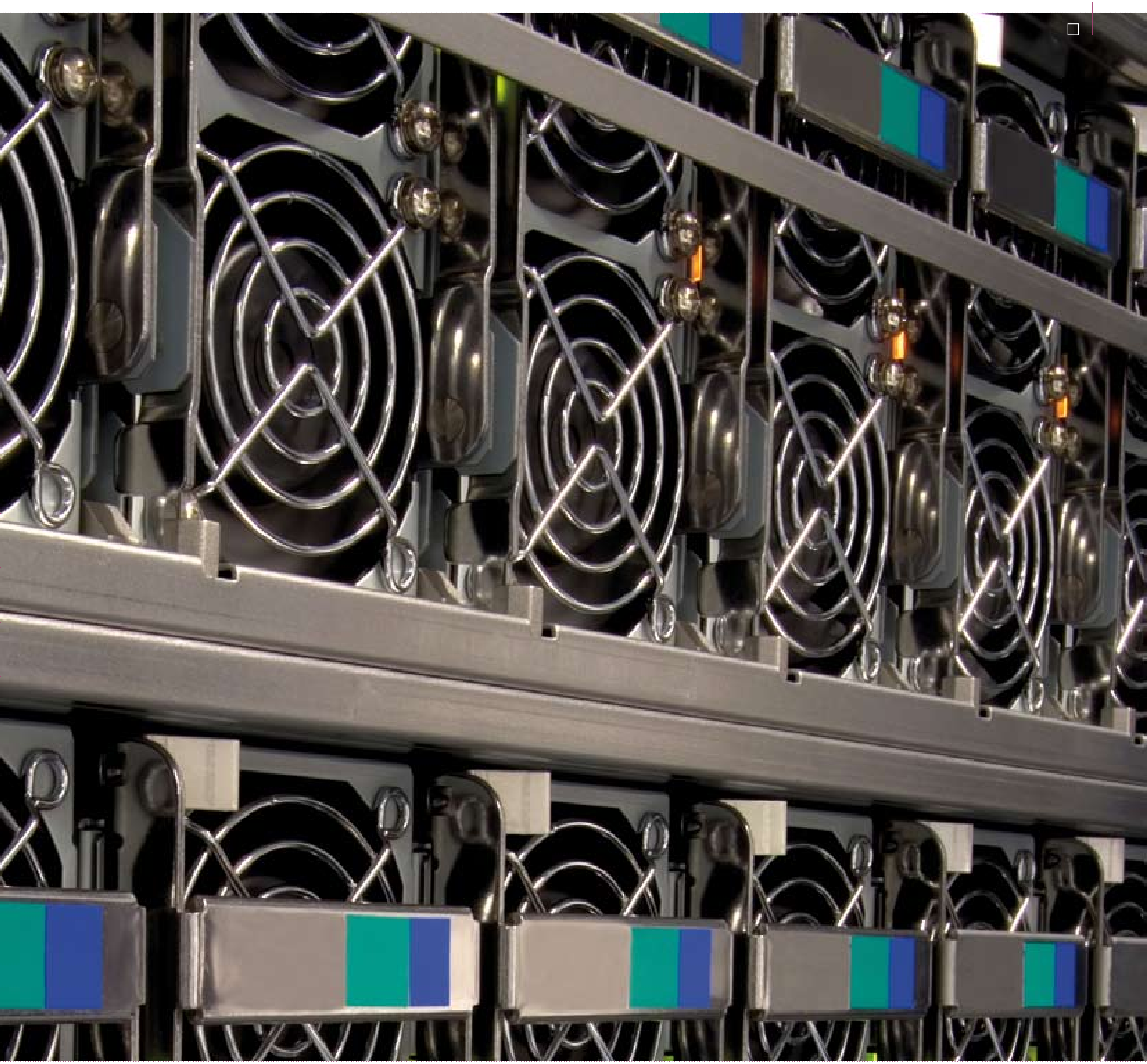


Distributed and Connected

Remarkable achievements in technology, engineering and process improvements shaped the 20th century. Industries pursued larger and larger projects in the search for economies of scale. Globalisation has increased the pace of standardisation and simplification, with the winners being lean and mean.

Current technology advances seem to be enabling a paradigm shift with more and more local activities becoming globally connected. Business value is shifting from ownership of traditional economic resources (physical, plant and equipment) to intangible resources such as relationships, intellectual property, and brands. Could these paradigm shifts help to take efficiency to a new level?

Investors lost a lot of money betting on the dotcom boom of the late 1990s. Nevertheless, the Internet revolution has created new sources of value and new business models. What impact will these have?



Global and Local Collaboration

Unfortunately there is still no way to buy a working "Beam-me-up-Scotty" system. So it remains cheaper to move electrons down a wire, or send waves through air and space, than physically move people and freight. So why don't we all stay at home, and live by wire? Why don't we buy more locally produced goods?

This re-think is already happening, but in niche markets. In many countries anyone can set up a company using a credit card and a telephone. This in turn means that any house can become a factory.

"It's back to the days of the village blacksmith. Every village used to have a blacksmith who made what people needed. Now kids use Internet routers to get what they want."

"The 'micro manufacturer' is coming back. Musicians buy cello strings from Denmark and special bicycle spokes from Switzerland, because that's where they are made by small specialist firms."

Our experts made the point that local production is perhaps best suited to premium niche goods by craftsmen and artisans. After all, why would you want to make your own computer when companies like Dell enable you to build a custom machine cheaper than any individual could ever match?

And mass manufacturing is now developing a business infrastructure that supports a degree of specialised localisation to respond to ever more demanding consumers looking for unique products.

"You can buy handmade shoes from Estonia by getting a 3D scan of your feet and then using it to order shoes online. Each one is handmade, but doesn't cost much. It's mass customisation."

Some business models now rely on the bulk shipping of standard components and materials, with the customisation – rather than complete manufacture – happening locally.

"All high-end cars are made to order," an auto enthusiast in the group noted. "If the basic core is shipped from the factory then local centres can customise."

The same principle applies to spectacle lenses, where a factory mass produces blank lenses which are then ground locally to order. Custom fitted hearing aid manufacturers use a similar system.

"Better to ship supplies of clay and make tiles to local design, than ship in finished tiles in bulk."

However if a business deals in intellectual property rather than in physical goods, it is far better placed to do business seamlessly around the world.

"Movie-making is already distributed. Different talents from all round the world can work together, editing, post-production, special effects, music recording and so on. The time taken to make the movie is reduced. When it's global, people are working 24/7."

The facilities that enable businesses to create distributed and localised manufacturing hinge on well-running information and communications technology infrastructure. This is essential to allow businesses to co-operate across continents.

And the need to operate at both global and local levels is blurring some traditional boundaries.

Distributed Power Generation

Distributed power generation uses a range of technologies to produce electricity locally rather than by large centralised stations. These can be located close to where power is needed, provide customers with greater choice, and enable local control and more efficient waste utilisation to boost efficiency and lower emissions.

These technologies include solar photovoltaic systems, concentrating solar power collectors, fuel cells, natural gas engines, industrial turbines, micro-turbines, energy-storage devices and wind turbines. They can be combined to provide consumers with continuous power, backup power and remote power, and to ensure supplies during peak demand periods. They can be installed directly on the consumer's premise or located nearby in district energy systems, power parks, and mini-grids.

Combined Heat & Power (CHP) technologies have the potential to take all these technologies one step further to reduce pollution and emissions. They capture the waste heat generated during the production of electricity and use it for domestic or industrial purposes. Approximately two-thirds of the energy used to produce electricity by standard power plants is lost as waste heat. CHP can raise the overall efficiency of power generation to as high as 70 per cent. ■

Distributed Manufacturing: Biofuels

The approach to biofuel development differs around the world. In the United States corn and soybeans are the principal agricultural crops grown to produce biofuel. In Europe theses crops are rapeseed, wheat and sugar beet, while Brazil uses sugar cane and South-East Asia favours palm oil.

Countries such as India and China are developing both bioethanol and biodiesel programmes. India is extending plantations of jatropha, an oil-producing tree that is used to produce biodiesel. Both the Indian Ministry of Defence and the Indian Railways are releasing land to encourage the local growing of jatropha as a source of biomass for biofuels.

This diversity in base products stimulates small-scale, regional biofuel production for local markets. The brewing of alcohol, the pressing of corn-oil, even a biorefinery can – in theory at least – be run from someone's back garden.

Encouraged by tractor and agricultural machinery producers in the last few years, the small-scale production of biofuels has become widespread. In the USA, biofuels have been produced at home and on farms for the last five years. Farmers in Poland and the Czech Republic are installing biodiesel facilities, and in Sub Saharan Africa there are extensive programmes to develop community biofuel production to complement the use of biomass as a fuel for cooking. In the UK, a group of companies have come together to form North East Biofuels (NEB) with the mandate of creating a liquid biofuels supply chain and the promotion of small-scale biodiesel production kits. ■

"Dell assembles laptops locally, rather than in China. In the US, UPS ships faulty computers back to Dell, but it takes days to get there and days to get back - eight days total. So now Dell engineers sit in the UPS building fixing simple faults. Nike stocks shoes in UPS warehouses."

The UPS model of in-house repairs highlighted the difference between business cultures in different countries.

"India is a country of mom and pop shops. There are no returns in India. In the USA, 30 to 40% of goods bought are returned. The mindset is different. There is a thriving business in India repairing cell phones which in 95 per cent of cases can be made to work again just by cleaning contacts."

Given the pace of change in countries like India, it is unlikely that old ways of doing business will remain the same, and many developing nations are looking to leapfrog developed countries by learning from their mistakes.

"There is an opportunity here for India to do it right; perhaps with high tech virtual companies."

Exploiting new distribution models requires some fundamental changes in other aspects of business as well. As one expert put it: "We also need to re-think our attitudes to cost of production versus cost of storage."

British record label Nimbus is addressing this by producing all CDs to order – by recording to blank discs instead of pressing in order to avoid having recorded CDs stocked in the warehouse. The major music and movie companies are moving towards selling entertainment on-line, for consumers to download at home and burn

to blank discs. Getting paying customers to do the work will save companies money on production, warehousing and shipping.

So are consumers going to change behaviours and make different choices that impact the way business operates?

“Some things you are prepared to wait for – some not. Who’s winning – IKEA or the local cabinet maker?”

There was broad agreement that if we are better informed then we might make different choices.

“New Zealand fishermen sell to US restaurants. You order by the web and they send the fish by Fedex. Scotland sends shrimp to Finland to peel. There is now a move to have labels with a product’s carbon impact. How much carbon does it take to import kiwi fruit from New Zealand, move them round the UK by lorry and then drive them home from the supermarket by car?”

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Telepresence

Telepresence is the next evolution of video conferencing. It uses high-resolution panoramic cameras and large screens to create a much more life-like environment than was possible with older technologies. Hidden cameras, speakers and microphones transmit and receive high-speed data streams to add subtle communication cues, which aid collaboration.

Effective telepresence requires the installation of dedicated suites where conference attendees sit facing large screens. These are mirror images of each other – a layout that creates the feeling everyone is in the same room. In some installations participants have felt that they could reach out and touch the other person as they would in a real meeting.

In contrast to older video conferencing systems that used public telephone networks, telepresence installations use dedicated fast global networks to send and receive extremely high quality video and sound. Though installing these dedicated facilities is expensive, an increasing number of organisations are using them to replace business travel.

Applications for telepresence go much further than for just teleconferencing. Another application of the technology could be for subsea work or inspection of pipelines. Telepresence systems for inspection and teleoperation systems for repair and maintenance would realise significant cost benefits.

Mobility and Networks

During World War II there was a slogan "Is your journey really necessary?" Perhaps it now needs reviving.

Video conferencing boomed during the first Gulf War when business executives were frightened of travelling, but the impact was short-lived.

Telecommuting seems an obvious way to save time and reduce travel costs and pollution, just as the paperless office was supposed to save trees. In reality the paperless society generates more paper, printed out for safety in case the computers crash.

Will telecommuting be more successful? The social aspects of working in an office environment force any discussion about telecommuting to move beyond simple energy saving.

While telecommuting makes it easy never to leave the house, it is exactly this "benefit" which has a very real negative aspect.

"Why do silicon valley IT engineers travel to work every day? They are at the forefront of IT and telecoms technology with broadband at home."

"People are becoming more isolated in the virtual world. They talk through e-mails and text messages."

"The Silicon Valley engineers have houses near the offices and they want the human interaction. Work is social. Telecommuting is not."

Discussion turned to which technologies could enable more distributed activity and have the potential to reduce the need for the movement of people and goods.

The cell phone, it was generally agreed, is changing the world in ways never dreamed of when the first chunky units were launched some 20 years ago.

"What do we all carry? Keys, money and a phone. The phone is a survival tool, not a phone. It's a device that transcends space and time. In Uganda workers send money back to relatives in the village. Until recently children carried the money, but were robbed. Now the worker buys credit and sends it by mobile phone message to a centre in the village, which hands over the cash. So the phone becomes an ATM machine. It's the next generation of infrastructure."

Business is not the only area where fundamental societal changes may occur. The widespread availability of online mapping systems – which can show almost anywhere in the world in very high photographic detail – has enabled virtual tourism.
"Humans want to explore, but some will be happy to explore by computer, using systems like Google Earth."

"With Google Earth we can look down into the gardens of Presidents, or what armies are doing in different parts of the world. It's very embryonic at the moment but I think it's going to take us to some very, very interesting places."

But for every plus there is a minus. That's why it is so hard to predict future trends.

The Internet is continually fighting a losing battle against fraud, scams and spam. Sending an "old-fashioned" fax is now more likely to grab attention than writing an e-mail.

“In twenty years’ time writing letters will become popular again.”

Most of us take it for granted that the world is changing faster than ever before. But not everyone agrees.

“Technology change has been roughly constant over the past couple of hundred years. It’s a conceit to think that our technology today, computers, internet, that sort of thing, is just so much greater than what we had in the past. A lot of the IT advances that have happened in the past have actually caused us to lead a more fast-paced life, and that has had a significant impact on family life.”

There was concern, too, that new technology is being foisted on us solely to suit manufacturers. Devices that were once simple are now complex, which means there is more to go wrong.

“No-one wants a toaster to have an IP address. But it may soon be cheaper to use components that provide for network access than leave it out. It will be too cheap not to do it. It’s now very difficult to buy a standard ordinary toilet seat in Japan. They all have electric heaters, even SD card slots to play bird song noises.”

IT and new technology take time to tame. Children learn how to handle them at school and from friends. Then they teach their parents.

So where does this leave older people with no children?

“Grey power is important. Retired people have time on their hands. Previously old people needed kids to feed them. Now they need them to explain how the Internet works.”

“For the first time in humanity we’re on the verge of a situation where every human mind on the planet can be connected together.”

“We’re moving into this world where we’re able to deliver information friction-free, and people are able to communicate without barriers. Look for example at peer to peer file sharing.”

Intellectual Property

New technologies that allow the free flow of information are a double-edged sword. On one hand they enable the "friction-free" world, but on the other hand they also open a Pandora's box of issues concerning intellectual property (IP) rights. An expert IP lawyer pointed out that there's a whole history of several hundred years of intellectual property rights rules that are designed to create barriers to this free flow of information.

"If intellectual property rights prevent technology from continuing to develop, we will be doing ourselves quite a disservice in the end. There are so many important and lawful uses for this kind of technology, and sharing information, that we have to make sure that it remains open and free for people to be able to communicate and exchange information."

The copyright term is continuously being extended in the United States and other countries. This has implications in many areas of society – particularly education – for the public domain information that we all own."

Digital Rights Management

Digital Rights Management (DRM) is a widely used term to describe methods designed to prevent people making unlimited digital copies of movies and music in an age where digital technology has made it easy for people to share their collections with each other over the Internet.

The media industry, particularly record companies and film studios, has developed DRM in response to the new, unprecedented danger that new technologies pose to their business. In the past, although copies of analogue cassettes were possible, the quality of each subsequent copy would fall. With digital reproduction, the thousandth copy is the same quality as the first copy.

After several false starts trying to apply DRM to purchased media such as music CDs, it is now most commonly applied to downloaded media. DRM technologies vary in how they work: some limit the playing of media to one device only or prevent playback if subscription payments are not maintained, for example. Each new DRM technology has to survive an onslaught of hackers who object to the nature of the restrictions imposed. Despite various international laws that make it illegal to circumvent DRM, the hacking community has usually found a way to disable it. ■

"It's important that we have a robust and vibrant public domain, but if we continuously extend the term of copyright protection we're preventing things from falling into the public domain. We're preventing people from having access to ideas, access to text."

"Digital rights management (DRM) technology lets publishers and software providers encode music or movies or books and essentially lock them up and disable lots of uses. People are unable to make a copy because of DRM. But copyright law allows for making copies of things for personal use. So we're protecting copyright but preventing the flow of information."

It's a safe bet that everyone has some electronic media in their home that they can no longer access – old and obsolete word processor discs or Betamax video tapes. DRM adds legal barriers to the technical obstacles.

"When things become obsolete we need to be able to unlock that technology and get access to the data inside. But the laws and the technology are making it impossible for people to do that unless you're a very sophisticated hacker. And then you've still got problems with the law."

"Intellectual property rights are supposed to be about a balance between competing legitimate interests; the right of the public to access information, but provide an economic incentive to create, to encourage entrepreneurship and innovation. When we go too far in creating intellectual property rights we actually stifle the very creativity and innovation that we encourage."

Implications

The discussion turned to the implications of what a distributed and connected society might look like, and conversation focused on the health industry.

“Currently, we have medical tourism, where people travel long distances for surgery. The Internet will make remote surgery possible. Australia already has remote diagnosis, where remote hospitals don’t have specialists. There will be robots that do the surgery. Currently our robots are junior doctors. But they could be real robots. It will happen. DIY diagnostics with home cameras will distribute healthcare.”

“Today you have to go to a health professional, ask for a test, be screened perhaps once a year for cancer or a number of other diseases, and wait many weeks for the results in some cases, only to be called back for a re-test and so on and so on. In the future, healthcare will be highly distributed. It will be in people’s homes, you will do it almost all yourself, and you will only go to a physical facility for a very profound intervention, like a major operation.”

“In the UK, the NHS Direct service encourages people to phone and describe their symptoms. Usually the nurse at the other end just says, ‘Oh, you had better see a doctor’. It would be better if the caller had a sensor that lets the nurse tell them whether they really need to see a doctor.”

“We shall see a lot more DIY diagnostics. The best way to scan for breast cancer is once a month. Home PCs already have scanners. They could scan for diabetes, too.

“For weight-induced diabetes, prevention is cheaper that treatment. But do you need distributed low-cost imaging for this? Imaging can give false results, which cause distress. Using biomarkers instead of imaging will be more reliable. Buy a kit and test for illness, like a pregnancy test kit, but for illness. Schemes like that could arrive when the health insurance companies offer a discount for people who self-diagnose.”

The ease of access to information in a distributed and connected health system may give rise to a new disease. One of our experts thought that in the future we might well see “affluenza” – people who are well but worried.

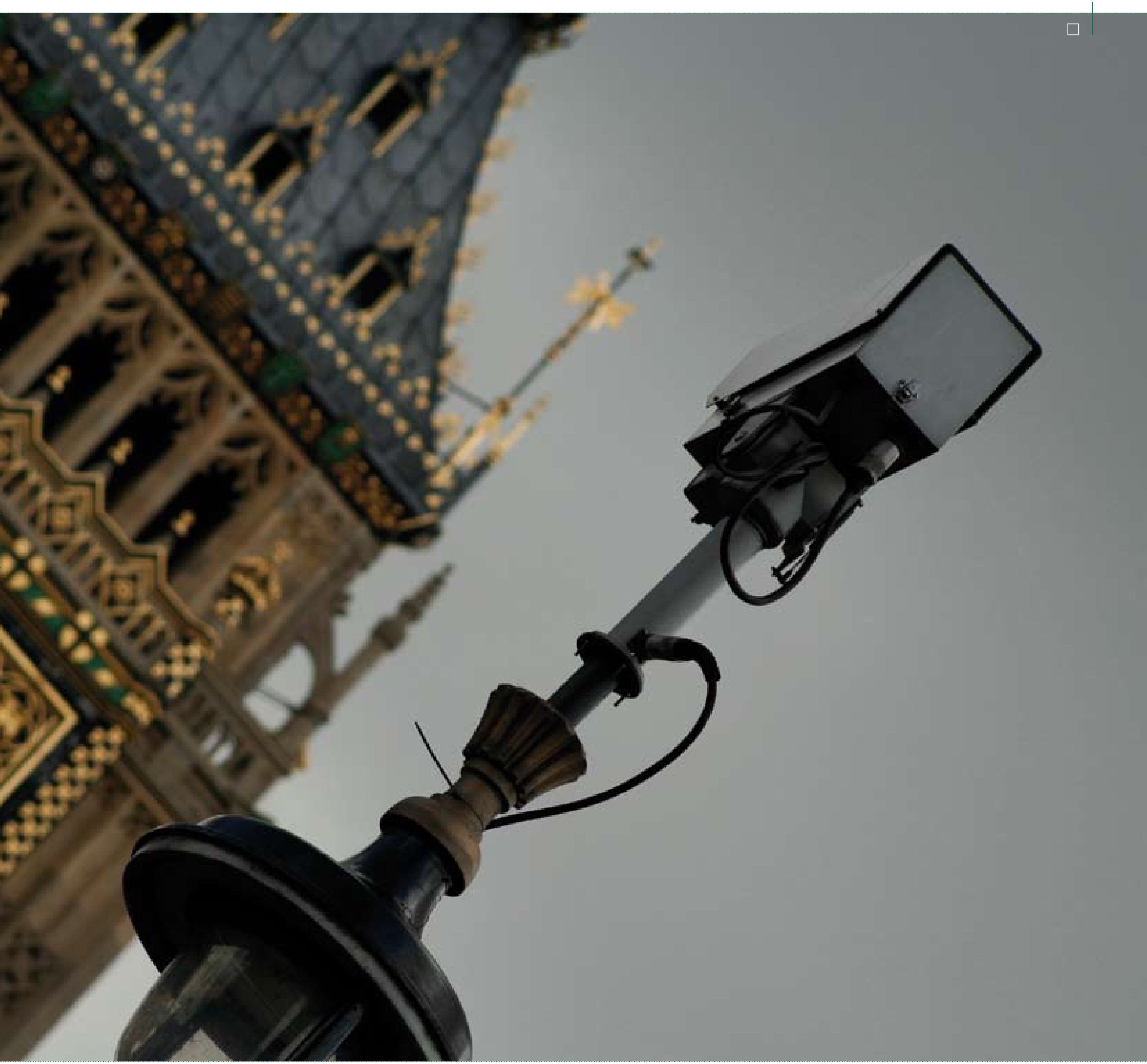
Track & Trace

No Hiding Place

This section looks at how technologies to track and trace goods have already combined to impact everyday life across the world. These often offer substantial benefits for global trade, but sometimes produce unintended consequences too: particularly the danger that these same technologies can, in the wrong hands, be used to infringe privacy.

It has become cheaper, easier, faster and more energy-efficient to move or hunt for electrons than for physical objects. Reducing both the cost and risk of goods getting lost (either accidentally or by deliberate acts) has helped boost international trade. Individuals can identify where things have come from and make better-informed choices about what they choose to buy. However, individual privacy is harder to protect with increased levels of surveillance and connection of databases. So do the benefits of tracking and tracing outweigh the downsides, and where do our experts see further advances?

The military has for many years relied on surveillance by satellite to keep one step ahead of the enemy. Similar images are now available to the general public and anyone can go online to Google Maps, type in their street address and view high-resolution images



Tracking Systems

Autonomous devices about the size of a deck of cards and weighing approximately 100 grams can be used to track anything from people and vehicles to shipping containers and other high-value cargos.

Also, technology exists for the tracking hardware to record details of movements even when the device is out of range of a cellular network – for instance when mounted on shipping containers at sea. Once back in the range of network coverage, the device immediately spools logged data up to the database so although the device was not continuously tracked, the full journey details are still known.

The technology also exists to enable the conditions inside shipping containers, the condition of the contents, and the integrity of the container itself to be mentioned.

Tracking can also tell you when high-value vehicles such as performance cars or mining equipment is switched on or moved, helping the police to prevent theft or retrieve stolen property.

Track and trace is also being offered as part of mobile phone packages: once the phone is switched on, the phone can be tracked within mobile network cells making it possible to locate the whereabouts of the owner.

of their neighbourhood as viewed from space.

The benefits of satellite imaging go far beyond virtual sightseeing, and many sectors such as agriculture are applying the technology in novel ways.

"Brazil uses infra-red satellites to know which plants need watering."

Other applications of military satellite technology are finding their way into many areas of society. Global positioning system (GPS) devices are being built into a range of portable electronic devices, and our experts predicted some novel applications.

"GPS tracking will tell a cell phone network where you are. It will detect when you go into a showroom to buy a new car and start talking to a finance company before you make an offer."

"And suppose you have an appointment with your friend at six o'clock and for what ever reason you land up in the hospital. You don't have to call up your friend. Your intelligent software agent will use GPS to figure out you are in hospital and send a message to your friend saying that you won't be able to make today's appointment. Small things like this will go a long way to helping society at large."

It turns out that small things – quite literally – are critical for some of the more recent developments in tracking technology.

The relatively new technology of radio-frequency identification (RFID) uses electronic tags which store coded identification information, like an electronic version of a military 'dog tag', making it easier to track and trace goods, animals or people. The tags can have a small battery that transmits the data, but more often the tag is a passive transponder, which uses radio energy transmitted

by an interrogating device to re-transmit the ID signal back to the interrogator. Tags are getting simpler and smaller, so they can be integrated in labels or even swallowed with food.

The technology has the potential to redefine the word "lost"' and one of our assembled experts pondered whether RFID would mean the end of missing airline luggage.

"Tracking and tracing is currently by bar code. It is only over the last twelve months that there has been a standard protocol for RFID. There has been no real incentive to move from bar code to RFID. But Florida law now compels pharmaceutical drug tagging, right up to consumption. Then it will be used for packaged food. There was a scandal about contaminated olive oil. RFID lets you know were your olive oil came from."

Tracking the source of products may be one of the drivers for RFID adoption around the world.

"It's very difficult to track where fuel came from. In Europe, palm oil for biofuels will have to be traceable back to a sustainable source."

"Taggers will use liability as justification. You can use tagging to detect counterfeits. In future, all goods will be tagged. Wal-Mart is just waiting to pull the trigger."

One expert believed the reason that RFID tagging is not more widely used at the moment is that it is not ready for mainstream adoption.

"Let me tell you a dirty secret about RFID tagging. The technology doesn't yet work reliably. It has to have a tuned circuit, and any metal near the tag detunes the coil. But we are now getting technology to get over that."

There is also the potential for RFID to find its way into increasing the efficiency of transportation networks.

"RFID works up to one metre. Radar works up to one kilometre. A device with a radar reflector or transponder can identify itself. This could change road taxing, or count the number of cars in front of traffic lights to adjust the lights - so that if there are ten cars waiting in one direction and one in the other, the lights change for just long enough to let the cars through."

The ability to track things as they move, not just on roads but also around the world, is a real competitive advantage for many businesses.

"The major thing that's allowed Amazon to take off in Europe is a very small button on the website that's called 'Where's my Stuff?' The reason people are willing to trust Amazon and buy their products isn't to do with price or anything else, it's to do with choice and the ability to know at every moment in time whether their book will arrive tomorrow or the day after, whether it's lost in the system, whether it's reached Belgium or not yet, and so on."

RFID is essentially a passive sensor that contains pre-programmed information about the object it is attached too. Active sensors, however, are able to relay changing information, and a myriad of applications are being developed across sectors to exploit this capability.

"A diagnostic sniffer could sniff wine in the cellar and tell you when it's ready to drink. Or tell when a piece of fruit is precisely right. It could be applied at the farming stage, for picking, or for transportation or retail."

Computer and Machine Vision

Using computers and imaging technology to recognise and act upon visual information can be a powerful tool to improve manufacturing processes and provide critical support for activities such as security surveillance.

Computer vision uses artificial systems to obtain information from images without the need for human analysis. Simple programmes are able to identify the existence of pre-specified objects in an image. More sophisticated systems can recognise and classify objects to produce 3D imaging of people and other biological systems.

Machine vision uses these techniques and applies them to activities such as security and manufacturing. For surveillance, machine vision is helping authorities to monitor and predict crowd behavior. Increases in computing power combined with high-definition machine vision means ever-greater volumes of visual data can be analysed to observe a scene and anticipate events about to unfold. This technology is being used effectively to control risky situations, such as at busy railway stations or sporting events, where individuals are potentially at risk of attack or injury.

Advanced data mining systems, pattern recognition and digital geometry have enabled the analysis of very sensitive security situations where life-threatening activities can be pre-empted by anticipating actions. In less sensitive situations, individuals can be identified and their mood determined from the capture of facial images.

Machine vision can also be combined with computerised control systems to increase the productivity of automated manufacturing systems. Cheaper computer hardware has encouraged the use of these techniques, driven by the need to improve the quality of manufactured parts.

Whether it is the medical industry's desire to reduce liability, or the consumer market's need to lower costs, 100 per cent part inspection is becoming the norm. When failures can jeopardize customer relationships or even result in a product liability lawsuit, manufacturers are seeking to meet ever more exacting quality standards. ■

“You can use sensors to find out the quality of grass. That lets you optimise a cattle farm.”

“A research lab in Australia is already using a wireless sensor network to check the temperature and soil moisture remotely and see who is walking where. Cows are tagged with smart neck collars and a mild electric shock can steer the cow to eat the correct grass. You can get rid of fences and put flow meters on troughs or keep bulls apart. It is smart farming. The only difficulty is to stop the smarter cows biting each other’s smart collars off.”

“The sensors are solar powered. Most have been running for 18 months. It’s the world’s longest running wireless sensor network. Information hops from sensor node to node. Cameras let you see who’s walking around. The biggest engineering problem is how to keep bird droppings off the solar cells.”

Tracking and tracing people, and their behaviour, is now big business but there is a dark side to this brave new world, of course.

“When the police interview a suspect there are one or two officers in the room and behind a two-way mirror there is a team of data miners talking to the interrogator by ear piece. The team is mining through a terabyte of data, cross-checking. ‘Press him on that, ask him again about this’ they say, always looking for contradictions. Non-contact polygraph lie detectors detect voice tremble.”

Revealing the truth in a closed and controlled environment is not the only sensor application being explored by law enforcement agencies.

Smart Dust

Smart dust devices integrate sensing and communication technologies plus a power supply into inch-small devices that can be used to gather data, run computations and communicate that information by two-way band radio.

They have been made possible by the rapid convergence of three key technologies: digital circuitry, wireless communications, and micro electromechanical systems (MEMS). In each area, advances in hardware technology and engineering design have led to a reduction in size, power consumption, and cost. Recent breakthroughs in production techniques means that these “motes” could eventually be the size of a grain of sand.

“Smart dust” devices, as tiny wireless micro-electromechanical sensors, can detect things such as light and vibrations. Arrays of them can be scattered across wide areas, able to communicate between themselves to detect movement, for example.
They can be used for a range of commercial applications from detecting manufacturing defects by sensing out-of-range vibrations in industrial equipment, to tracking soldiers in the field and patient movements in a hospital ward to within a few centimetres. They could even be used to remotely locate and fire upon moving targets on a battlefield.

"We already have speed cameras and automatic number-recognition cameras. Soon we'll be able to track every vehicle movement in an entire country."

It is not just vehicles that can be tracked with cameras. It was pointed out that London is the most monitored place in the world, with 4.5 million CCTV cameras. However images are not the only thing that can be monitored.

"Microphones around US cities already listen for gun shots." While some new sensor applications may sound appealing, further discussion began to reveal the unwelcome side of this type of technology.

"Fingerprint entry control to vans is bad news. Criminals just use a bolt cutter to take off someone's finger and they are in. There's always a way round security."

"Cut your index finger and you will have to make a fingerprint impression with your forefinger. From then onwards recognition must be by forefinger."

"And what happens if the wrong picture gets linked to a fingerprint by computer error? 'I have no idea how to fix it,' an immigration official said when this happened to me. 'Write to your Home Secretary' was the best advice he could offer me."

"An RFID implant can provide security. You are a swipe card to get into your house."

RFID

Radio frequency identification (RFID) is a data collection technology that uses electronic tags for storing data. The tag, also known as an "electronic label", "transponder" or "code plate", is made up of an RFID chip attached to an antenna. Transmitting in the kilohertz, megahertz and gigahertz ranges, tags may be battery-powered or derive their power from the RF waves coming from a reader device that can decode the information stored by the tag.

Like bar codes, RFID tags identify items. However, unlike bar codes, which must be in close proximity and line of sight to the scanner for reading, RFID tags can be embedded within packages and transmit their data actively. Depending on the type of tag and application, they can be read at a varying range of distances. And RFID-tagged objects rolling on a conveyer belt can be read many times faster than bar-coded boxes.

The next generation of RFID will combine tag technology with different kinds of sensors. This allows the tag not only to report the simple information time and time again, but also to transmit changing data. For example, an RFID tag attached to frozen food could report temperature readings over time to ensure that the food was kept sufficiently cold.

That concept met with some disbelief.

“That’s the craziest idea I’ve ever heard. I’d rather someone picked an ordinary lock than cut off my arm to get easy electronic access.” If RFID tagging is adopted widely and moves into everyday use, criminals won’t need to break into your house to uncover personal secrets. The ability to scan an RFID object from a distance raises some worrying issues.

“Anyone with a reader will be able to work out who you are and what you own.”

“As long as you have inefficiency some people will take advantage.” “We’re also going to see an explosion of stealth technologies where companies, communities and individuals try and cover up elements of what they’re doing.”

“There are still all kinds of regulatory and ethical questions, about how we use the tracked data – like what can be remembered and what applications can run against those databases. This is all coming, and soon.”

Despite some of the worrying aspects of track and trace, one thing became clear.

“We’ll become vastly better at managing, moving and storing information than doing anything physical.”

Water, Health & Biotechnology

Freshwater is the liquid of life. Without it the planet would be a barren wasteland. The supply of water is finite, but demand is rising rapidly as population grows and as water use per capita increases. In an effort to spur action to meet the impending crisis, the UN General Assembly has proclaimed the period from 2005 to 2015 as the International Decade for Action: "Water for Life".

In theory, 0.5 per cent of the world's water is available for human use every year – equivalent to some 10 cubic kilometres of freshwater. If evenly distributed this would provide each person with roughly 1.5 million litres of freshwater per head per year for drinking, industry and agriculture. So what is the problem?

Freshwater supplies are not distributed evenly geographically throughout the seasons, or from year to year. For example, the Congo River and its tributaries account for about 30 per cent

of the entire African continent's annual runoff, but the watershed contains only 10 per cent of Africa's population. Two-thirds of the world's population, around 4.4 billion people, lives in areas receiving only one-quarter of the world's annual rainfall.

Throughout much of the developing world the freshwater supply comes in the form of seasonal rains. Such rains, as in the Asian monsoon season, often run off too quickly for efficient use. For example, India gets 90 per cent of its annual rainfall during the summer monsoon season, which lasts from June to September. For the remaining eight months of the year, the country gets barely any rain.

In addition to seasonal rainfall, pollution of rivers and lakes reduces accessible freshwater supplies. Each year large volumes of wastewater are discharged into rivers, streams and lakes. Before it can be used again in the evaporation and precipitation cycle, about two-thirds of the world's total annual useable freshwater runoff is used to dilute and transport this dirty water to the sea.

World population growth and rising demand per capita are creating water shortages in many western countries. Globally, the annual population increase of nearly 80 million per year implies an increased demand for freshwater of about 64 billion litres a year – an amount equivalent to the entire annual flow rate of the Rhine River.

One of the Technology Futures workshops was held in Bangalore. A reservoir not far away is well known as a nature reserve. But there was no chance to visit. The area had been closed off by the military because of a dispute between neighbouring states over who owns the water rights.

When two states of the same nation need soldiers to keep the peace over water, you get a feel for what can happen between different countries.

As someone at the seminar reminded:

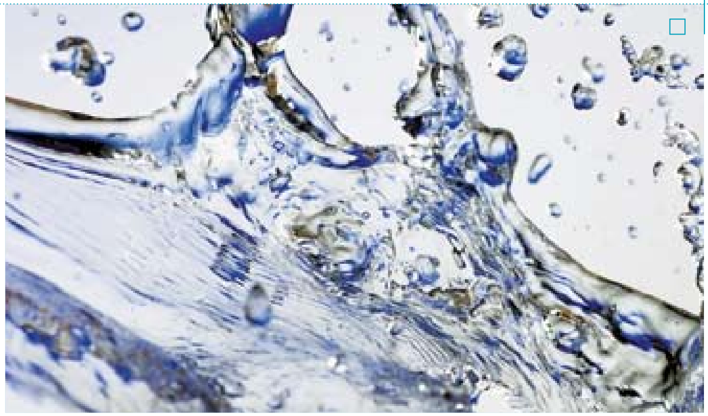
"Less than one per cent of the world's water is fresh. In twenty years water scarcity will be one of the major problems. In the future, wars will be fought over water. China and Tibet are already at loggerheads over a lake."

The biggest problem with fresh water is that it is not distributed evenly, and it cannot be found where it is needed the most. What's now happening in Singapore gives wider hope for a happier future, though.

"Singapore got its independence in 1965," a native Singaporean explained. "The country has no natural resources and has to rely on its ability to trade and create other sources of competitive advantage. Singapore has not got a drop of oil, and no water of our own either. But we have the third largest oil refinery in the world. We import oil and refine it. We have had to import water too, from neighbouring Malaya."

Now Singapore is removing its reliance on other countries for water by developing large-scale reverse osmosis technology that provides water clean enough for drinking.

"Singapore started membrane de-salination when the cost became manageable compared to the payment being made to our neighbours. Reverse osmosis is more cost-effective than distillation, but less so than digging it up of course."

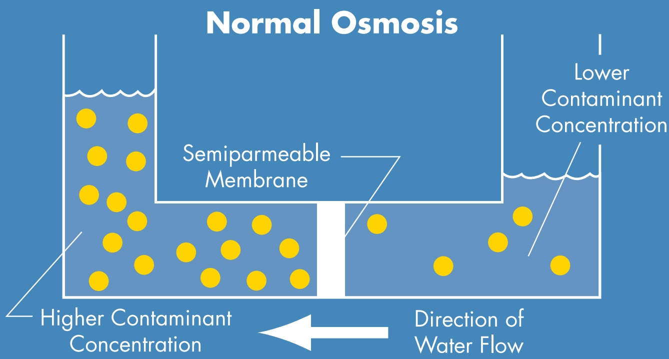


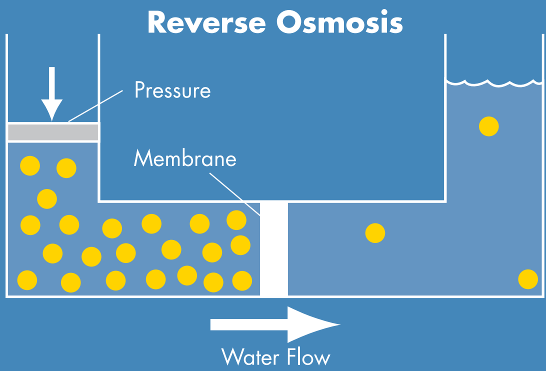
Reverse Osmosis

Reverse osmosis is an extremely effective way to filter and purify water. As the name suggests, the process is a variation of osmosis – the movement of water (H_2O molecules) across a semi-permeable membrane separating two bodies of water with different concentrations of dissolved particles, minerals and microorganisms. During osmosis, the water molecules from the "purer" water will pass through the membrane to dilute the "dirty" water. In conditions where water pressure is removed from the equation, usually by artificial interference, this process will continue until both volumes of water reach the same concentration of H_2O molecules.

Reverse osmosis applies pressure on the "dirty" water to counter the natural flow of osmosis. In doing so, the process - called ion exclusion – allows the water molecules to pass though while preventing contaminants from doing so.

Industrial processes using reverse osmosis have been developed which can take in sewage and turn it into drinking water that exceeds the World Health Organisation requirements for drinking water. ■





"The same membrane can be used for purifying waste water. Waste water is re-cycled. Singapore now recycles half its sewage. The recycled waste water is used for chip fabrication plants and to fill reservoirs."

The system now provides between 30 and 40 per cent of the clean water in Singapore. It also adds a level of security to the country by removing the risk of water shortages caused by political conflict. Singapore's reverse osmosis system could work anywhere and solve a wide range of problems.

"Many water wells around the world become salty as the fresh water table level goes down. This water is not as salty as seawater; it has around half a per cent salt, compared to seawater's three per cent salt. This brackish water is much cheaper to desalinate than seawater."

"But then desalination is a stopgap, not the solution. We have to restore the water table. Perhaps we will end up having to move water from water-rich to water-poor countries just like we do now with oil?"

Transporting water over long distances would inevitably involve significant cost and be very energy intensive, but what are the alternatives? The issue of access to reservoirs raises the inevitable discussion about countries fighting over the availability of water.

"There's a lot of talk about water wars. It's not going to happen. Technology will make water cheap enough. People need to be made more aware of what they are using, though."

Too true. Nations that traditionally have had plenty of water have been profligate with it. The current level of waste is not sustainable, but the approach to solving the problem differs around the world.

"Why do we flush toilets with drinking water? Because US regulations say the water supply must be sterile. It's crazy. A reed bed on the roof could provide the same filtration locally."

"It's illegal to catch rainwater in Denver. It's illegal not to catch water in Chennai. Houses in India have two connections, one for salt water and one for drinking water. Brown water systems are easy to build when starting from scratch."

"In Sydney, water rationing is making people aware of how much they use. You improve everything you measure."

The issue of water use is not limited to private homes. Heavy industry, manufacturing and even the generation of electricity wastes water.

"The biggest water consumption is in making electricity. Manufacturing wastes water too. There's an opportunity here for building lean manufacturing processes to sell to other countries when water becomes scarce there."

"We are moving into a resource-constrained society, where answers can't be 'we can't do that'. Things will change."

Access to clean water is inextricably linked to the health of a population, and our experts pointed out that the biggest killer along the southern border of China and Burma is diarrhoea. Millions of people die each year from drinking impure water.

"Illness may not kill but it lowers productivity. Thirty per cent of Africa has AIDS. How can it become more productive? Imperfectly targeted vaccines can make things worse, by lowering resistance."

This focused the discussion on how developments in medical technology could address some of today's major health issues. Gene therapy – intervention to replace diseased genes – is one area of research that has the potential to produce some startling results.

"Children who were born today will expect when they're teenagers to be able to grow a new kidney, in the same way that if you break a leg the hospital puts in a metal plate to allow your bones to re-knit."

"But I'm not sure that big cures for major diseases will bring a lot of improvement." Major diseases are not the only threat: a rapidly spreading epidemic – such as avian flu, could have very serious consequences for society.

"With ten per cent dead would there still be electricity? There would be civil unrest and everyone leaps in their car. That's the opposite of quarantining."

"When the SARS epidemic hit, one whole hospital in Singapore became a dedicated quarantine centre. Everyone was given a thermometer to check temperature. Infrared detectors at the airport looked for incoming passengers with fever. Health officers called up to check people who were quarantined. One couple was caught outside their home and put in jail. If a similar infection hit Indonesia or China, could the government cope?"

Biotechnology

The use of biotechnology is widespread and is already having an impact on a large number of traditional fields such as medicine, pharmacology, agriculture, food technology, chemistry and environmental protection. And developments today mean it could be applied to many exciting new fields in the future.

The scientific community believes that the technical hurdles still facing biotechnology are surmountable. The bigger challenge for specialists in this field may be overcoming social fears about what may be seen by some as interfering with nature. Will society accept tissue engineering and stem-cell science as the basis for the body to provide its own spare parts (autologous chondrocyte transplantation (ACT)), or the in-situ growth of new teeth using regenerative techniques?

Biotechnology

The impact of biotechnology on our daily lives will be far greater than in the past. We shall benefit from the potential of regenerative medicine and have access to new cellular therapies. Plants and animals will be used as bioreactors to produce drugs cheaply.

Medical treatment will be tailored to the patient to a far greater extent than today, and improvements in medical diagnosis will alter our lives and allow us to take greater responsibility for our health. We shall also be able to purchase food products with designed health benefits going far beyond their nutritional value. Biotechnology will be the driver for transportation fuels and the source of new chemicals that will impact the whole of modern society.

Massive increases in computing power, coupled with advances in robotic's are enabling researchers to understand our world at a level never previously explored. In biotechnology a major revolution is underway, driven by the ability to sequence the genomes of many species – including humans.

"Gene sequencing is about identifying genes. It's cheap. The price of gene sequences is coming down so fast it is too cheap to meter."

"Sequencing is the easy part of understanding biological functions. We've sequenced the genomes now of about 300 living things. Our knowledge grows by the day, and the number of people who are entering the field is very encouraging."

Genetic Engineering in Agriculture

Genetic engineering is the manipulation of genes with the objective of introducing new characteristics or attributes physiologically or physically. In agriculture it is used to modify the genetic compositions of plants, animals, and microorganisms. The number of genes that have been isolated by scientists and are available for transfer is growing daily.

The most widespread application of genetic engineering in agriculture is to introduce traits, such as the ability to withstand insects, drought, herbicides and viruses, into crops. Thousands of such products have been field-tested and over a dozen have been approved for commercial use.

Currently, one field of research is focusing on how to use genetic engineering to increase the nutritional qualities of food crops or to build in other traits for novel uses other than food. Proteins in foods may be modified to increase their nutritional qualities. Oily crops like corn or rapeseed, which at present are used mainly for margarine and other food oils, can be modified to produce fatty acids for detergents, substitute fuels and petrochemicals, or other specialty chemicals like bio-insecticides.

"It's easy to predict sequencing because you know how long it will take. Then the real work starts. You have to start knocking out genes to see what happens. You can then intervene to make a gene active so that it produces protein that does something useful and predictable. Biotechnology is cheap once you get the first step. Twenty years should bring enough understanding to breed custom plants bespoke or tailored for the job."

The breeding of plants designed for specific conditions will change agriculture forever. As one expert pointed out, cynics say that the best way to be a successful farmer is to win the lottery first. The next step is to keep farming until the money runs out. The new science of genetic engineering could change this by providing genetically modified (GM) crops that adapt to and flourish in particular local conditions.

"GM can make plants grow faster and more resistant to salt. If plants were salt tolerant we could use brackish water. GM can engineer drought tolerance, too."

"Plant science is about which gene turns on what effect. GM can give us higher yield from fuel crops and better bugs to break down carbohydrates. GM may give us microbes that can ferment more efficiently. Biotech is a huge force to improve conversion. GM can make plants more efficient at photosynthesis."

"Genetic engineering can control the time when fuel crop material starts processing; like a time bomb that starts to eat itself. But you don't want it to start eating itself while the material is still in storage."

Gene Sequencing

Chromosomes are formed from two coils of deoxyribonucleic acid (DNA) - a nucleic acid that contains the genetic instructions used in the development and functioning of all known living organisms. Genes are the DNA segments that contain the instructions needed to construct other components of cells, such as proteins and RNA molecules.

DNA sequencing, achieved by the Human Genome Project, determined the exact order of the 3 billion chemical building blocks that make up the DNA of the 24 different human chromosomes. The resulting DNA sequence maps are now being used to explore human biology and other complex phenomena.

The difficulty with gene sequencing is dealing with the vast amount of data that is generated. While the human genome contains over three billion nucleotides, it is estimated that less than two per cent of these directly affect the production of proteins. Increasing computer speed is the key to faster sequencing as even small bacterial genomes have millions of chromosome combinations.

Nevertheless the speed of sequencing is rapidly accelerating and experts are predicting that the cost will drop to the point where it will be too cheap to measure. Currently it takes a small team of scientists two months to sequence an individual's DNA.

While sequencing the human genome has attracted much attention, many other species have also been sequenced. ■

"GM is not a magic bullet, though. It can improve things like demand on soil so that the crop needs less fertiliser. The effects are marginal but all add up."

The potential applications of genetic modification are not just found in agriculture. We were reminded that there are as many microbes in the human gut as there are cells in the human body. An expert in gene sequencing highlighted the potential of modifying these microbes to perform new roles.

"It may one day be possible to engineer a bug that lives in our stomach and de-salinates water. So we would have in-gut de-salination."

"But GM has had a bad press. The lobbies against GM are powerful. Mention GM and many people will immediately worry about 'Frankenfood' - food that has been created by a team of Dr Frankensteins, who then lose control of the monster they have created."

"The genetic engineering backlash will die. The benefits will be proved. Actually all crops are genetically modified. It's just done naturally, by selecting the best breed for the job and then breeding more."

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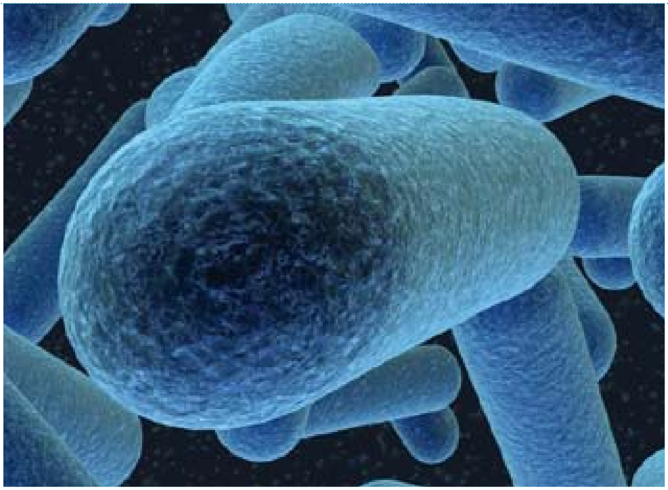
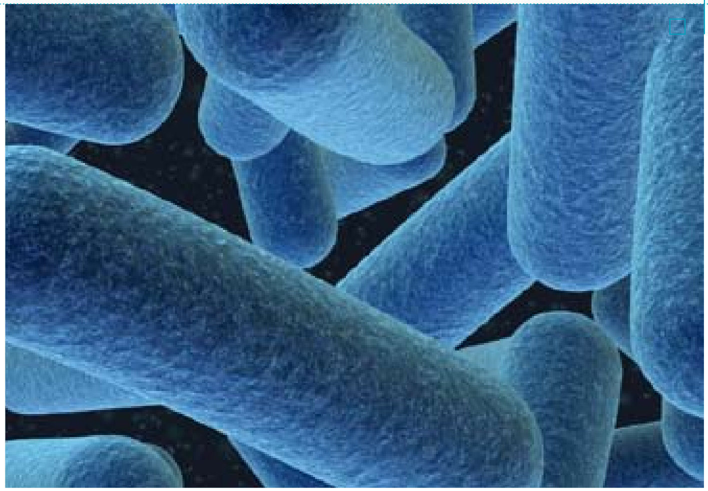




Gene Therapy

Genes are responsible for the production of proteins, and different combinations of genes produce similarly different proteins. Proteins form the cell structure and maintain most of the processes for enabling life in the cell. Genetic disorders arise when altered genes produce proteins that cannot perform their normal roles.

Gene therapy replaces individual defective genes that cause disease. It works by identifying the defective gene responsible for the condition, and then introducing a "normal" gene to replace it.

The gene is inserted into the cells by piggybacking on another molecule called a vector. This is most commonly a virus that has been genetically engineered to remove the disease causing genes and at the same time carry human genes. Once the virus "infects" the human cells, the normal gene produces protein products which return the defective cell to its healthy state.

Understanding the functions of all the human genes by using gene sequencing techniques is key to the success of gene therapy. It is currently best used to target conditions that are caused by a single gene – other conditions that rely on multiple gene interactions are harder to work with.

Gene therapy promises single-shot injection treatments that have the seemingly magic power to cure diseases and regenerate cells.

There are now hundreds of gene therapy trials underway, some of which have met with varying degrees of success in areas such as cancer, deafness, Parkinson's disease and diabetes.

However, many current techniques mean that a patient must have a large number of ongoing rounds of treatment in order for the disease to be treated effectively. And challenges remain. Research is underway to better understand immune systems that can adapt to and attack viral vectors that have been used before.

Concluding Remarks

After a series of intensive and enlightening discussions about different aspects of technology, our experts were asked to draw the threads together and consider the probable impact on the energy system over the next 20 years.

These sessions mixed gloom and optimism in equal measure but all agreed that litttle would be achieved without collaboration between business, government and technologists. There was general agreement that technologies exist that can make the difference – the question is whether society will take the necessary steps to deploy these technologies to have mass-market impact.

Society

The energy system was the focus of much of the discussions, and the overwhelming importance of oil kept coming up.

"Around 95 per cent of all mobility is powered by oil. The world is running out of oil, at least easy oil, there's lots of difficult oil. A chart of finds shows a peak in 1990. We don't know how much is left to discover. But the warehouse is getting empty."

"Americans in particular first caught a warning glimpse of the future with the oil crises of the 1970s. Drivers emptied their tanks while lining up at the pumps for enough fuel to get to the line for the next pump. Since then even the whisper of a rumour that fuel supplies will be interrupted is enough to create fresh lines."

"We have all grown very rich on the back of oil fuels. It can't go on. It's not sustainable. Survival is now about adaptation."

In some industries new business models can be developed in co-operation with competitors – the software industry is a prime example of this. However oil is so critical that regulators are very wary of energy companies working together.

"Anti-trust law makes it hard for oil companies to work together. So we need government to handle it. To meet demand we will need something other than oil. People don't care where fuel comes from. You could make it from table-cloths."

"Is society going to accept the need to dig up Canadian prairies, should we grow rather than dig? Will the public accept the idea of farming marine algae in the sea?"

While there was much discussion about the need to develop new sources of energy, there was also debate about ways of reducing current consumption levels. It was noted that the vast majority of people – in most societies – have no idea how much they consume every day. The suggestion was made that there were considerable gains to be made from measuring consumption.

"If we knew how much energy, how much water, how much electricity, how much gas, how much fuel we consume and the miles we waste, the kilometres we travel, and the things we throw away that could be re-used, if we could actually could see those losses, understand those losses, we could take steps to change our patterns of living."

The imperative to measure extends beyond the simple calculation of energy consumption and wastage.

"There's a real need for a carbon footprint calculator. As someone said earlier, you improve everything you measure."

This echoed another ever-present theme at the workshops – climate change and the environment.

"When Hurricane Katrina went through the Southern States of the United States, it had a profound effect on a few people. But many more have started to see climate change and environmental issues as Hurricane Katrina in slow motion."

However, while many people see a need to act, there are many historical examples of societies failing to work together even when its in their best interests to do so. Behavioural sciences demonstrate that appropriate incentives or punishments are needed to stimulate collective action.

"Trying to solve the CO_2 problem by convincing people to do the right thing is dangerously naive."

"You can reduce consumption through policy measures – drive slower, don't drive into the city, do this, do that… But it is a short step to tyranny – you cannot drive in this city. And if people are educated it's harder to have a totalitarian government."

Regulation was viewed as one of the key drivers that had the power to tackle climate change.

Participants suggested that putting a price on the carbon we emit – through carbon taxes, carbon trading schemes or personal allowances – is an essential step to address global warming.

"The planet is currently emitting 8 giga tonnes of carbon every year. A realistic carbon price would be $30 a ton and producers may have to bear the cost."

"Even a carbon tax of $50 a ton of CO_2 adds only between $5 and $10 to a tank full of gasoline. This will not be enough to change behaviour."

"Perhaps we should be measuring cars in miles per CO_2 emission, not miles per gallon."

"A carbon tax could change the balance. We've got to work with what we've got, not go looking for new things. We've got to stop waiting for a miracle because that holds things back."

It was pointed out that some politicians are already taking significant steps in the right directions. And while it was acknowledged that in most cases one person acting alone couldn't change the impact of energy use, two examples were given which gave pause for thought.

"Individuals can make the difference here. Ken Livingstone stepped outside the Labour Party to push the congestion charge in London. In California Arnold Schwarzenegger got fed up with President Bush and is going it alone."

Discussions returned to oil.

"We should set a floor price for oil and make it sufficiently high to generate the confidence needed to invest in long-term alternative energy projects."

It is often said that necessity is the mother of invention. Coal-to-liquids technology has been available since the 1930s. South Africa took it up and made it work because the rest of the world would not supply oil to the country."

"Government intervention can help there. Government could turn on a subsidy. The US military already fly B52 bombers on bio fuel and gas-to-liquid fuel. This will drive down the price. The US military fuel bill is $7 billion a year."

"If the EU and USA got together things would accelerate. You could build a facility to produce billions of gallons of ethanol a year for the price of the Iraq war. Or you need something like the stupidity of going to the moon. They got there, and look at all the technology that fell out."

One challenge when responding to climate change is that it is difficult to see an immediate impact of actions taken. Out of sight is all too often out of mind.

“It’s easy to clean smog in cities because it’s visible, but it’s difficult to ask people to act on something that will happen in 30 or 40 years. It needs a mindset change. At least people now see oil as expensive.”

“Brownouts make people aware of power supplies. But even blackouts are not sufficient to get people to change because they are temporary. People don’t change their light bulbs because low energy lamps cost twice as much.”

“But too many people still think that global warming is about rescuing a few polar bears from ice caps.”

“And without China or India on board, Kyoto-style agreements will go nowhere. In twenty years, greenhouse gas emissions will be dominated by the US and China. China is building a coal-fired power plant every week.”

Time is a key factor in any attempt to respond to the challenge of climate change, alter behaviour and introduce new infrastructures and technologies.

One expert suggested that humanity has ten, perhaps 20, years to make significant reductions in greenhouse gas emissions before the world enters a phase that’s going to be very unpleasant for millions of people.

This time scale is a critical issue because the oil industry has a long lead-time to bring new technologies to market. Solutions need to be developed now for implementation in the near future.

“In the pharmaceutical industry an invention takes ten years before it can be used. Electronics come to the market much faster. New oil technology takes 25 years to mature. Gas to diesel conversion was developed in the 1970s but the plant to do this is only now being built. A project like tar-sand extraction takes fifteen years to get up and running. Oil shale rights in Canada were sold in the 1950s and people are only now getting into it.”

Perhaps we need to change some of our priorities and only a shock will make that happen.

“What the US spends on pet food annually is sufficient for everyone in the world to have basic health care. What it spends on cosmetics is sufficient for basic education for everyone on the globe. Society is not yet prepared to make the sacrifice needed to find alternative energy sources. When will society be ready? When there is a disaster and that will happen before the oil runs out.”

“When there are dreadful events, people will start to be scared. The fear factor is a very strong political influence. A shock is necessary to make people make a difference.” ■

Technology

After many technological possibilities had been looked at, it was common ground that there is no single magic bullet to fix the world's problems. Nevertheless, combinations of existing, improved and new technologies can make the difference.

"Give scientists a challenge and a little bit of money and they will come up with an answer."

There was little debate that global warming is one of the greatest challenges the world faces..

"We have to figure out a way to capture and remove carbon from the cycle."

Our participants had plenty of ideas about how to achieve this.

"Sometimes two solutions work together. You can pump CO_2 underground to get oil out, and the CO_2 remains trapped underground."

"In the next 20 years we could see the conversion of carbon dioxide to hydrocarbon. The device could use solar energy and some new kind of electro-catalyst based on the development of nano-materials, which are able to convert carbon dioxide back to hydrocarbon. This would close the cycle of carbon dioxide and maintain some use of fossil fuels. It's a way in which we can try to avoid some of the drawbacks of the fossil fuels because we will need them for some time still."

"Take CO_2 from a factory and use it to help algae to grow in a pond, perhaps. And then use the algae to make bio diesel. Or why not blow CO_2 into a warehouse to make crops grow faster?"

"If there is more plant growth because of global warming, that would make the environment self regulating."

The key to better understanding of global warming may lie in the development of fiendishly complex climate models. These in turn need extremely powerful and very expensive computers to run them - highlighting the need for collective action in solving these issues.

"With the development of radar, the Manhattan project that was created to build the atom bomb, and the pioneering work with computers at Bletchley Park, in the UK, done to crack the German Enigma codes, all noses were pointed in the same direction. They are not now."

The dilemma is that we may not even know what modern equivalents to these World War II concentrations of effort exist. Despite Official Secrets gags, a few clues leaked out into our sessions, though.

Quantum computing, could make data analysis far more powerful leading to much more faster analysis and processing.

"Think about it this way – if a periscope pops up in the Atlantic, you can be informed immediately. Now instead, of looking for periscopes, apply the system to detecting the start of a fire anywhere in a forest in Europe."

"We have more data from the Hubble telescope than all of our computers can process – we don't know what we know. Quantum computing could make the difference."

The power of new computing techniques would have far-reaching consequences. An illustration of this began, oddly enough, with fruit.

"The market for oranges today collectively predicts price based on weather. The group has a better collective sense of the future than the weather forecasters. If we could crack quantum computing we could capture that skill with a machine. We could predict the price of coffee or develop a system that breaks the game of chance. But it would decimate the opposition overnight because it's only when you have inefficiency that some people can have an advantage."

"If one F1 team had an aerofoil on their racing cars that gave a 10 per cent improvement none of the others could win. If Tiger Woods had a better golf club and won every time, what would that do for the game of golf? You either have to regulate or make it available to everyone."

As often happens when a group of experts from different disciplines gather together the discussions took some strange twists and turns.

An expert from a defense research organisation plotted out an interesting scenario for the next steps in augmenting human vision with a range of other inputs. The path started with current jet aircraft technology.

"It takes ten years minimum to train a fighter pilot to fly a $500 mln dollar platform that takes years to build. It's then trial by combat, person on person, and almost always a fight to the death. If you lose consistently, you will lose completely. Pilots rely on heads-up displays to give them an edge. But HUDs are not really there yet for cars.

"The technology is evolving through spectacles, to lenses, and then will eventually involve direct retinal image production. The goal then will be to induce image signals in optic nerves. The final goal, for way past 2030, is Matrix-style imaging awareness without having to create it in the first place. Then we will be able to combine the processing power of computers with our ability to interpret and act."

This triggered off more speculation about how people will interact with computers, both by "normal" means, and the not-so-normal means.

"By 2015 we will see voice recognition that really works. Existing systems don't. Google used a huge database of natural language processing to show that a computer can now equal human translation of text."

"One of my friends has implanted magnets in her finger tips to give an extra sense."

Why?

"She can tell when the computer is going to slow down because the hard drive is working to store data from RAM."

We never did establish why this made it worth the inconvenience and discomfort of having the implants.

“Microsoft has been experimenting with ‘life bits’. Everything that is recordable (videos, blogs, notes, photos, voice recordings and so on) is recorded for personal use, and then condensed into a searchable archive of life. So you don’t need to remember what you did.”

We did not establish why this would be a good thing either. But other ideas seemed more likely to be practically rewarding. For instance, the use of photo-catalysts in paint to take care of smog already is being done, the next step may be embedding catalysts into glass buildings.

Concluding Remarks – The Change Between Generations

The balance of world power is already changing. The collapse of the Soviet Union and the end of the Cold War set Russia on course to become a world power in energy supply. China is becoming a world power in manufacturing – and pollution. India is on a similar trajectory. Given the different cultural backgrounds and experiences of our experts, their thoughts on the developing world were revealing.

“I sometimes wonder where all the communists in China have gone! The country now has a ‘will do, can do’ attitude. People find a way. Bureaucracy is alive and well in China, though. And old China is filthy and inefficient.”

“India is much more nimble than China. There is a lot more R&D than in China.”

One of the workshops was held in India, and the discussion turned naturally towards the sub-continent.

“1992 was the turning point for India, with a liberalised economy. India now has a fuel policy for the next twenty or thirty years. The government wants big power stations, 400 MW each. But the ‘India Shining’ campaign, applies to some but not to others. There are still 125,000 un-electrified villages.”

It was acknowledged that the biggest issue facing India is constructing infrastructure. A prime example was provided in the form of Infosys – the Indian IT giant – which had to build accommodation blocks close to its campus as there were not enough hotel rooms. Despite this challenge, people felt more optimistic about India than about China.

"I'd bet on India for the future. The country has quality education. The universities are spectacular. Children are taught English. Intellectual property is honoured, whereas 20 per cent of components in China are counterfeit."

"Don't forget that the US used to be a pirate nation – it used to refuse to respect IP rights. In China and Korea, copying is a tribute. But the Chinese are now starting to recognise IP if only because they're developing IP themselves."

Today's children – many of whom are more ecologically aware than their parents – will one day become leaders and decision makers themselves. Then the future will be in their hands. They will handle things differently and the balance of power is changing here, too.

"The West is getting dumber and more decadent – children in developing nations are getting smarter. In the US there is no agreement on the science curriculum. There are deeply ingrained religious, tribal beliefs."

"The MTV generation multi-tasks, they do three things at one time. They find it difficult to do one thing at a time."

"Our children also know that the easiest way to recycle packaging is not to package things in the first place."

It is not just children who are embracing the power of the Internet. Those who have grown up during the Internet revolution from its earliest incarnations have learned that it is a powerful tool.

"Individuals re-wrote the music industry. They told the record companies that it was not about round discs, it was about experience that could be downloaded. Individuals are now re-writing the TV industry, with sites like YouTube, and the media industry with projects like Wikipedia, which put knowledge out. People know they will get something back some day."

"They use sites on the Internet that show how politicians voted on every issue, what questions they asked and what answers they got – so the votes and independence of the individual are tracked. Howard Dean used the Internet to get a groundswell of support for his presidential campaign."

"The future may be about giving up on things. There is no free lunch. We are on a huge learning curve."

"Ultimately we must develop the technologies that give people what they want, but cleaner. Invention has to make sense to those who benefit from it, not to those of us in the labs." ■

Epilogue:

So what's it to be? Business as usual and worry about the future later? Lock engineers and scientists in a room and throw in food until they come up with a magic solution to all the world's problems? Or buckle down to some uncomfortable cuts and compromises while hoping that the combination of a lot of different measures will add up to more than the sum of their parts?

You be the judge. Common sense suggests we should opt for the latter, so we have tried to distill all the disparate thinking down into a hit list of eleven achievable aims:

1) A home computer, with Internet connection and sensors, could be used for do-it-yourself health self-diagnosis. This would save on travel, give early warning of diseases, and take the load off busy doctors. The first priority is a standardised system and some kick-start encouragement, for instance from reduced health insurance premiums for anyone using the system.

2) Radio frequency identity (RFID) chips can tag the source of a product, and so fight fraud and counterfeiting. RFID technology could also make losing possessions nothing more than an unhappy memory. Just press a button and the lost item displays its location – no more lost luggage for one thing. One caveat though: beware of exotic schemes that use RFID body implants for personal identification or security. Although superficially attractive they can easily - and very painfully – be defeated by criminals willing to maim or kill to steal the implant.

3) So many home electronics now rely on a 12 volt DC supply, that it makes good sense to install one central mains-to-DC converter in the home or office, with a 12V DC supply bus running round the building alongside the AC mains. One master converter will waste less power than multiple converters in individual pieces of equipment.

4) High temperature superconductor cables can reduce power losses. They no longer need liquid nitrogen and should soon become a viable option for business and even home use, especially where power is locally generated.

5) Membrane reverse-osmosis technology is making desalination and wastewater purification more affordable. But it is still absurd to flush toilets with drinking water. Rainwater and wastewater collection for use where pure water is not needed could make huge savings on mains water consumption.

6) Measuring what we use teaches us its value. Easy-to-read water, electricity and gas meters would encourage us to waste less and spend less. By the same token, an easy-to-use carbon footprint calculator would encourage us to avoid unnecessary travel and buy local produce. For instance, avoiding shrimp that has been shipped abroad for peeling. A new standard for CO_2-per-gallon fuel ratings would encourage the use of cleaner cars and fuels.

7) Harvesting biofuel crops from an area the size of Texas could replace all the gasoline used in the USA – but the energy industry needs confidence to invest in the necessary processing plant, the motor industry needs an incentive to produce cars that can use the fuel, and drivers need to know they will be able to buy the new fuel at attractive prices. The widespread deployment of flexible-fuel engines, which self-adjust to whatever fuel they are fed, is an essential stepping-stone to the

future. Tax breaks, subsidies and a floor price for oil and gasoline would encourage industry and consumers alike to invest in alternatives to oil. These should include not just biofuel but also solar, wind and wave-power, and hydrogen fuel cells, initially for low power vehicles such as scooters.

8) So long as there is any chance that cold fusion could provide a safer source of energy than nuclear reaction, the topic needs independent government-funded research.

9) Taking lessons from history, we should re-discover the age-old use of shutters, awnings and insulation. We should site buildings more carefully to stop them getting too hot or cold, and so rely less on artificial heating and cooling. New solvents, which allow buildings and large structures made from composite materials to be disassembled and re-cycled, would encourage the use of composites for building. This would reduce dependence on steel and concrete that guzzle large amounts of energy during manufacture.

10) Most cars are big heavy boxes containing mostly air. Using a modular vehicle, which can be varied in size to suit the journey and number of passengers, is one better alternative. Having access to two or three vehicles and choosing the best one for the journey in hand is another. But the cost of road taxes and insurance would need a reduction tailored to the use of only one vehicle at a time. The ideal engine for this – or any future vehicle – would be a hybrid with batteries capable of driving the urban average of around 40 miles a day. Plug it into the mains for overnight charging and top it up with a solar panel on the roof. For longer journeys the car can function as a series hybrid, like the Toyota Prius, but using either gasoline or biofuel in a flexible fuel engine generator that charges the batteries and powers the motor that drives the wheels.

11) If Man can go to the Moon and put self-drive vehicles on Mars, surely he can devise an easy-to-install DIY kit that lets a solar panel store surplus power by feeding it into the grid on sunny and windy days, for cash credit against power drawn at night or on calm days? Current systems are far from DIY. ■

Implications for Energy

The Technology Futures programme set out to harvest insights, opinions and knowledge about probable developments in technology over the next 20 years from a variety of sources. Throughout the discussions the focus was on how technology can enable the energy system to respond to the challenge of meeting accelerating demand in a sustainable way.

We assembled over fifty experts from eleven nations across Europe, Asia, North America and Australasia. With such a disparate group of people spread across countries and disciplines, the conversations ranged far and wide. People came with their own ideas on how their knowledge related to the energy system.

Despite the variety of views, there was broad consensus on the following issues:

Rapid population growth combined with the industrialisation of developing countries is driving accelerated demand growth; the existing energy system will struggle to keep pace with this growth; environmental stresses (e.g. climate change) are increasing.

This led to common agreement on the desirability of shifting towards a low carbon, sustainable energy system.

The discussions explored potential ways in which this could be achieved: changes in the mix of energy resources being consumed; changes to existing and development of new energy conversion pathways; changes in the way energy is consumed. A common thread through all of this was the need to improve efficiency of energy use.

What also emerged was a clearer picture of the complexity of the challenge. Changes to the energy system rely on interactions between society, technology and business and, whilst governments can play an important enabling role, the difficulty in adapting existing infrastructure or building new infrastructure is a significant barrier to change.

There are also many interdependencies between the energy system and other industries: all human activity is powered by energy and consumes resources (water, land, minerals, oil, gas, etc.). Different activities, and hence different industries, are competing for these increasingly scarce resources and are accelerating the need for substantial changes in order to manage the impact on planet earth.

What was recognised was the scale of the challenge – the growth rates needed for renewable energy (currently 3 per cent of total energy production) to replace fossil fuels, plus the required speed of change to the infrastructure, means that fossil fuels will remain a significant part of the energy system for years to come. Management of the environmental impact of fossil fuels then becomes a vital and urgent issue, as was pointed out. "It has taken us 200 years to build the energy system. Significant change must happen in the next 20 years and we need to start now".

Modern society is changing, though, and the speed of this change was open to debate. There are two schools of thought. One holds that, despite the hype, the current speed of technology development is no different to other disruptive changes that societies have experienced. For instance, the telegraph, the railroad and affordable air travel each bought about unprecedented changes in society when they were introduced.

The opposing school of thought says that a new breed of technology is accelerating the pace of change, and that society in twenty years will look vastly different to the world today. If this is the case, then the stresses on the energy system and on the ecosystem can only increase.

This book explores where and how technology can contribute towards achieving this change; the outstanding question is whether society, governments and business can work together to rapidly adopt and deploy these technologies to enable their mass impact on the energy system. Change will be challenging but will create significant business opportunities for those who play a part. What is clear is that the ancient Chinese curse "may you live in interesting times" is very appropriate for the next 20 years – they will be very interesting times indeed. ■

Appendix

The Energy System Data

The Technology Futures book explores how the energy system might change over coming years. This appendix provides some background data on the energy system over the last 30 years and some projections of population growth and associated energy demand on a "business as usual" basis.

Consensus estimates expect world population to grow from 6.5 billion today to 9 billion people by 2050, with most growth occurring in the Middle East and Asia. By comparison, in 1970 the global population was 3.7 billion.

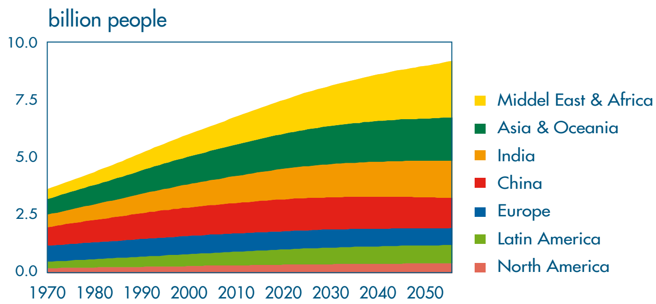
Historically, as countries develop and the level of GDP increases, energy demand has accelerated This phenomenon, known as 'climbing the energy ladder', implies that in a 'business as usual' world the combination of population growth and development will continue to drive growth in energy demand.

And as households get wealthier, the type of energy services and carriers they demand changes to reflect the more advanced uses for which they are needed (e.g. heating, air conditioning, greater use of transportation).

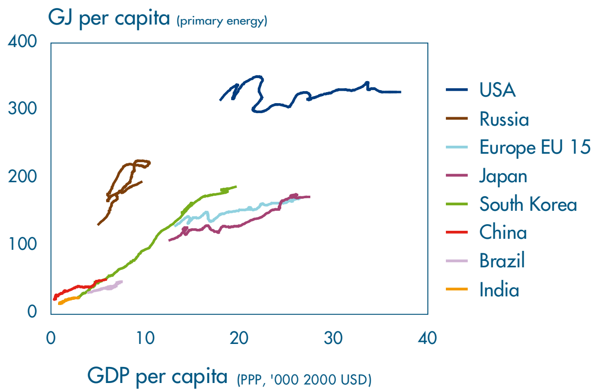
In recent decades the migration of populations to cities has continued. In 1800, just 3% of the global population lived in urban areas. That figure rose to 13% by 1900. In 2007, it reached 50%, with 1.4 million people moving to urban areas every week. Furthermore, it is estimated that 1 billion people currently live in urban poverty.

The shift to urban living will impact energy usage through changing patterns of consumption and an increased influence of city administrations on energy infrastructure.

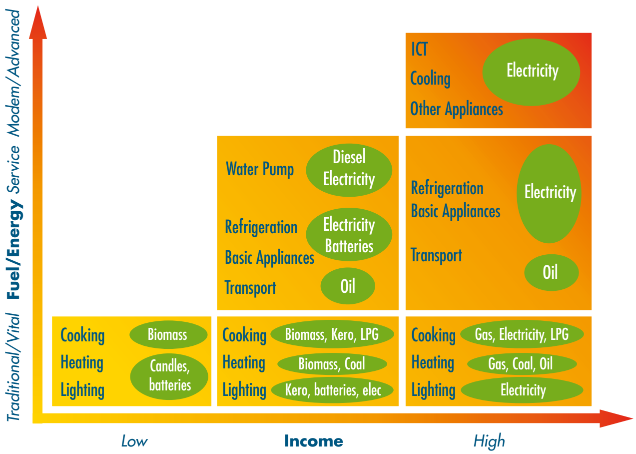
Population Forecast



Energy Ladder Demand/GDP

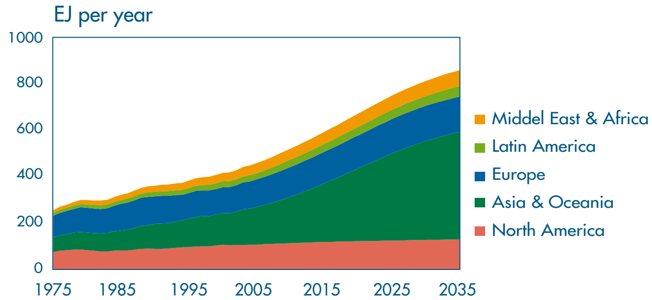


Energy Ladder Demand/GDP



Source: World Energy Outlook ©OECD/IEA, 2002, Figure 13.1

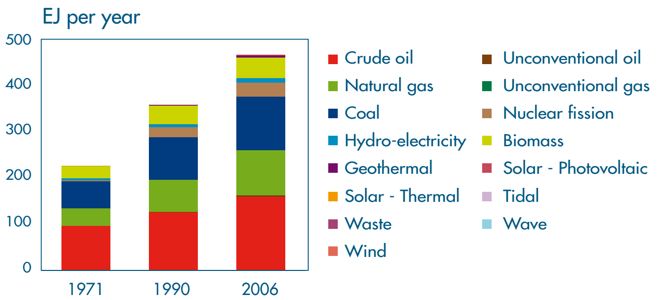
Business as Usual Demand



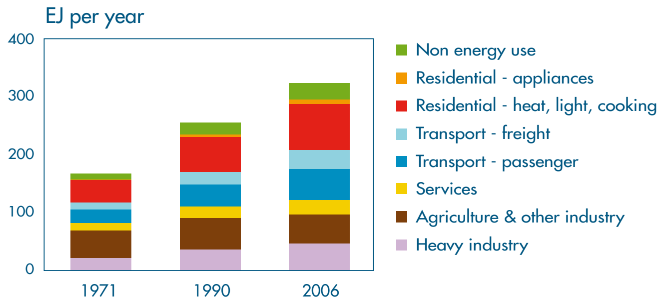
Historic Energy Data

From 1971 to 2006, whilst total annual energy consumed rose from 168 to 326 EJ, the proportion of energy consumed as a percentage of energy produced decreased from 74% to 68%, indicating a decrease in energy efficiency due to shifts in the energy mix. The historic breakdown of primary energy by source, energy consumption by carrier and energy consumption by sector are shown below for 1971, 1990 and 2006:

Primary Energy by Source

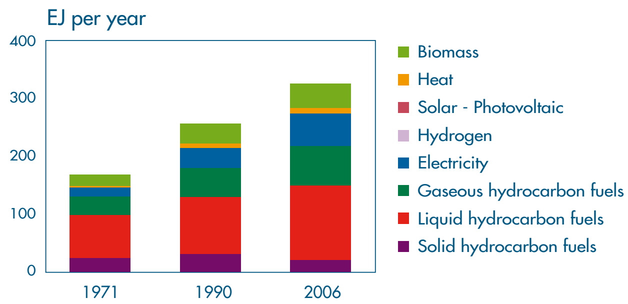


Energy Consumption - Sector

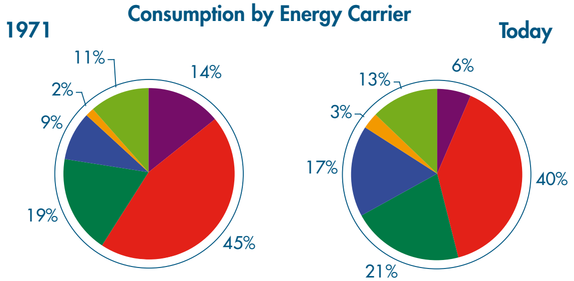


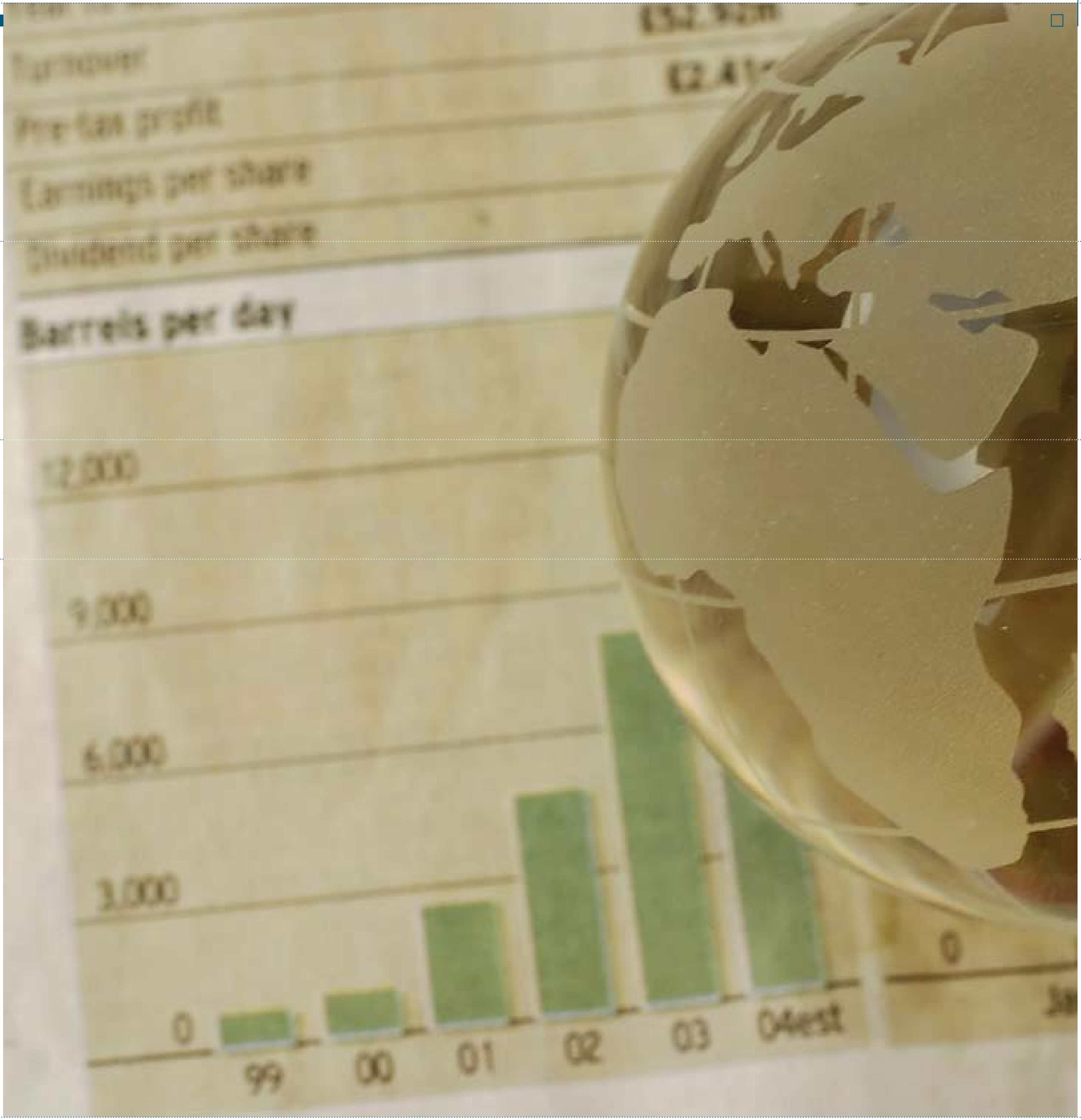
Energy Consumption - Energy Carrier

Total Final Consumption



Consumption by Energy Carrier




Turnover
Pre-tax profit
Earnings per share
Dividend per share
Barrels per day
12,000
9,000
6,000
3,000
0
99
00
01
02
03
04est

Glossary

Abbreviations

mt = metric tonne

ppmv = parts per million by volume

mbd = million barrel per day

boe = barrel of oil equivalent

kWh = kilowatt hour

CCS = carbon capture and storage

CO_2 = atmospheric carbon dioxide

Gt = gigatonne

International System (SI) of Units

GJ = gigajoule = 10^9 joule

EJ = exajoule = 10^{18} joule

MJ = megajoule = 10^6 joule

Conversion between Units

1 boe = 5.63 GJ*

1 mbd = 2.05 EJ/year

1 million cubic metre gas = 34 700 GJ*

1 million tonnes coal = 25 GJ*

1 kWh = 3.6 MJ

** This is a typical average but the energy content of a particular carrier may vary.*

Data Sources

The principal data sources used as inputs in the development of Shell's scenario analyses and charts in this booklet are:

- World Bank WDI
- Oxford Economics
- UN Population Division
- World Business Council for Sustainable Development
- Energy Balances of OECD Countries ©OECD/IEA 2006
- Energy Balances of Non-OECD Countries ©OECD/IEA 2006

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