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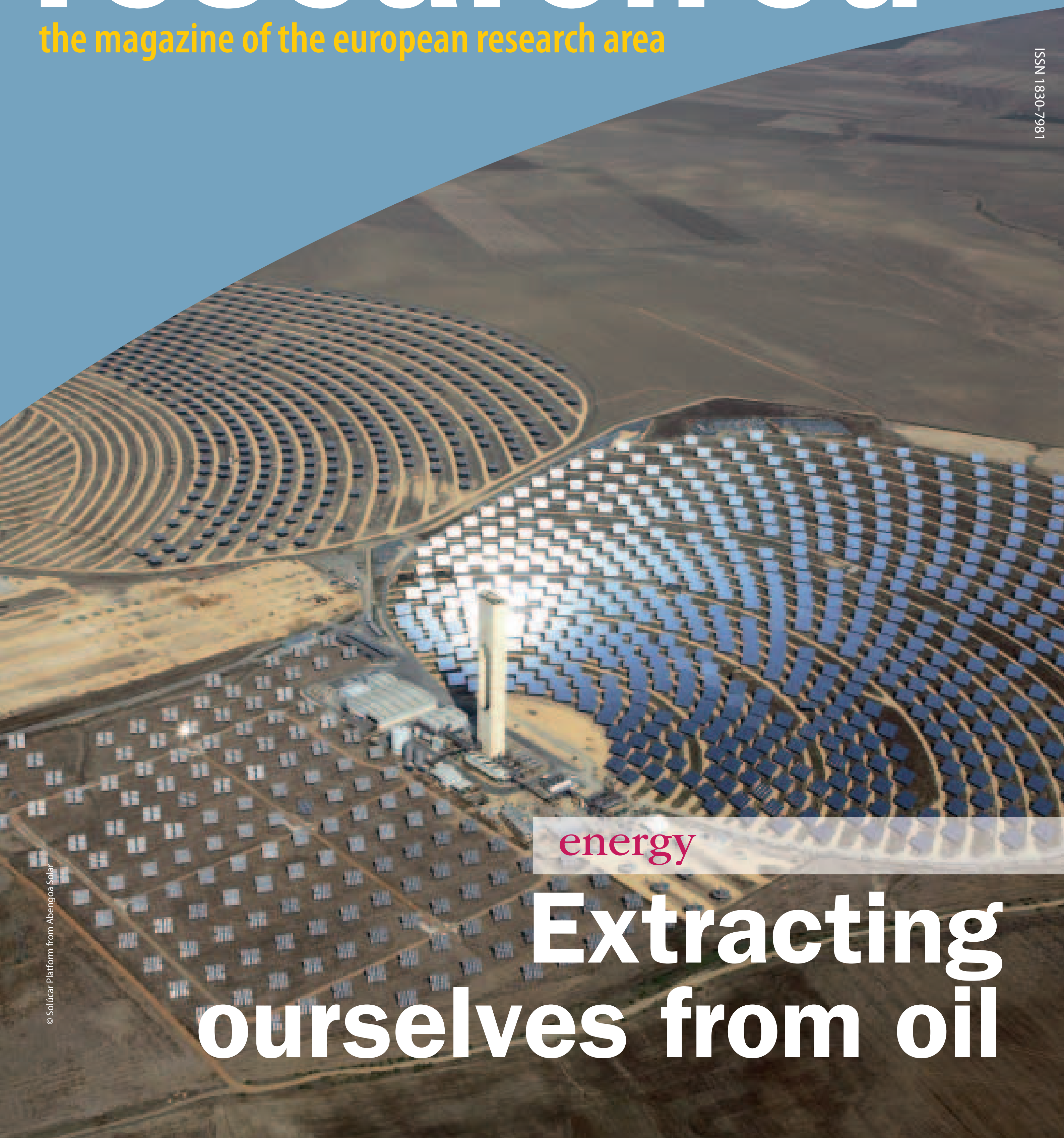

energy

Extracting ourselves from oil

*research*eu is the European Union's research magazine, written by independent professional journalists, which aims to broaden the democratic debate between science and society. It presents and analyses projects, results and initiatives through which men and women are making a contribution towards reinforcing and uniting scientific and technological excellence in Europe. Published in English, French, German and Spanish, with ten issues per year, research*eu is edited by the Communication Unit of the European Commission's Directorate-General for Research.*

editorial

Shedding light on the horizon

We are eating oil (see page 40). This issue is a reminder of the omnipresence of oil – or "black gold" – in our everyday lives. The symbolic US$100 a barrel mark and the proximity of peak oil signal the beginning of a heralded end. There is but one certainty: humankind and the planet are engaged in a process of metamorphosis. How will we live in the post-carbon society? This is the pertinent question, since it sparks so many different answers! In opening the doors of the laboratories, this issue shows that, initially, research is set paradoxically to strengthen the use of fossil hydrocarbons. Beyond that, the future becomes clouded and the scenarios diverge and intersect. No energy dominates and they all seem necessary. There is some light on the horizon, such as the recent *HyWays* European project that has concluded that hydrogen has a seemingly bright future. Its use could reduce oil consumption in the transport sector by as much as 40% by 2050. We also know that "agri" fuels are not the panacea, and that solutions will also come from the emerging countries.

But these many and very real possibilities ultimately fade into conjecture. What remains is the concern of the citizen who is already feeling the consequences of this major change in day-to-day life, with price rises, climate change, and depletion of resources. To the point where some are even reluctant to continue living as they do now… To all these people this issue will hopefully provide a little ray of hope. Current research looks very promising. The imminent change heralds a renaissance. A world that may not be better but that will be sustainable. Because it is either that or no world at all.

Michel Claessens
Editor in chief

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On the cover
Sanlúcar La Mayor complex near Seville in Spain, the site for Europe's largest concentrated solar power plant for electricity production (see page 24).
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Laying a pipeline near Sangachal, in Azerbaijan.

Meeting

There are few people today who still deny that humanity is facing a growing number of threats – or challenges, if you are an optimist. Eminent official institutions are joining social critics in declaring that our development is no longer sustainable and in stressing the need for radical change if we are not to court disaster. But what changes? Do we want more or less international trade and regulation? Which technologies and social practices should we support, and which should we resist? A frank and open debate that is free of taboos is needed if we want to agree a shared vision for the future. To contribute, albeit modestly, to such a debate, we put some questions, crucial to our collective future, to three leading international figures drawn from very different backgrounds. Each answered independently of the other. We then brought together their replies to offer the reader a mix of stimulating and very contrasting ideas.

the post-oil challenge

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Vandana Shiva, 56, is a doctor of physics and the philosophy of sciences. Of Indian nationality and a writer, ecologist and feminist, she is a leading figure in the international alterglobalisation movement whose commitment to nature and the oppressed has earned her many prizes. She heads the *Navdanya* association that is campaigning for an agriculture that respects the environment and is seeking to update traditional farming practices.

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Claude Mandil, 66, is an engineer and graduate of France's prestigious *Ecole Polytechnique*. He has headed the *Bureau des Recherches Géologiques et Minières* (BRGM), the French Oil Institute (IFP) and was Managing Director of Gaz de France. He recently retired from the post of Director of the International Energy Agency (IEA) that he had held for four years. He answered our questions in a personal capacity.

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Achim Steiner, 47, studied philosophy, economics and political science at Oxford University and at the *Harvard Business School*. He was Secretary-General of the World Dams Commission and for five years headed the IUCN (*International Union for the Conservation of Nature*), the NGO that is a reference in global biodiversity. Since June 2006 he has been Executive Director of the United Nations Environment Programme (UNEP).

Do you believe that the very high oil prices are due to circumstantial reasons or are they here to stay?

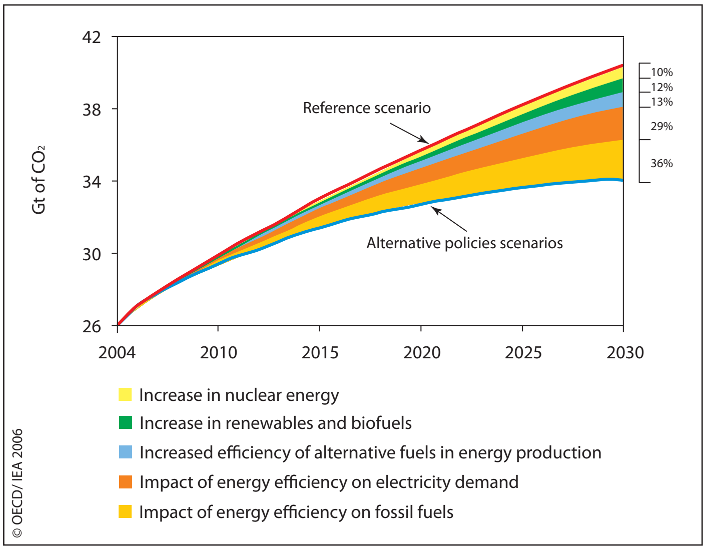
Vandana Shiva These prices are logical and not in any way circumstantial. All the independent experts say that we have already reached peak oil or, if not, are about to. As the main concern of oil companies is to maintain our dependency on hydrocarbons for as long as possible, they are notably unforthcoming on the exact status of their reserves. But we now know the truth.

Claude Mandil It is not impossible that, in the short term, if there is an economic crisis, we will see a very severe correction in oil prices. But I believe there is a very strong underlying trend towards expensive oil, not so much due to a lack of the physical resource as due to a lack of investment in extracting it. Most oil reserves are now in the hands of state-owned companies (in Mexico, Russia, Iran, the Middle East, etc.) whose priority is not to invest. We are witnessing a revival of oil nationalism within a broader context of energy nationalism that is even evident in some European countries. I would also add that the post-oil era is not for tomorrow. We are rather entering a period of scarcer oil with more difficult access and higher prices.

Achim Steiner The present high prices are the result of a combination of factors: the level of global reserves, global growth, and the policies of producer countries. But as an environmentalist and economist, I believe that the prices of fossil fuels should reflect the costs they inflict on the economy in the widest sense – and if this were to be the case, then I believe prices would no doubt be even higher. Because these fuels increase the quantity of greenhouse gases in the atmosphere, which will lead to an increased number of extreme events and rising sea levels, with a resultant loss of agricultural land and destruction of infrastructure. But their use also increases the level of pollutants that undermine public health in cities, and acidify the rain, thereby damaging productive ecosystems such as forests, lakes, estuaries and coastlines. We know that there are going to be fossil fuels for a long time yet, so let us cost them correctly so as to encourage the most efficient use possible and the development of alternative energies, from solar energy to hydrogen.

Do you, like the International Energy Agency (IEA), believe that a major increase in the use of coal is inevitable? Could CO_2 capture and storage (CCS) offset the disastrous climatic consequences of such a development?

V.S. An increased use of coal is only inevitable if we persist in wasting energy and if the economy continues to promote industrial solutions even when we could do without them. In that case, then clearly we are going to resort to coal as we run out of oil and gas. As to CCS, there is not yet any proof •••



Global reduction in CO_2 emissions possible in 2030 by combination of replacing fossil fuels and energy savings.
The International Energy Agency's reference scenario predicts a 55 % increase in world primary energy needs between 2005 and 2030, representing an average annual increase of 1.8 %. The alternative policies scenario calculates a global demand for primary energy increasing at the rate of 1.3 % a year over the 2005–30 period, which is 0.5 % less than for the reference scenario. A high-growth scenario based on the hypothesis of more dynamic economic development in China and India (an average of 1.5 percentage points a year above the reference scenario) puts energy demand in 2030 for the two countries together at over 21 %. As the graph shows, the efficiency of final electricity and fuel use represents two-thirds of possible reductions in 2030.

●●● that it works. What is more, introducing on an industrial scale gases or liquids where they do not belong – look at genes for example – never fails to have an impact on the environment. This will also have the effect of prolonging our dependency on fossil fuels when we should be promoting renewable energies – more time wasted for humanity.

C.M. The future growth of coal is evident. The Chinese, Indian and North American economies are massively reliant on coal that has all the desired qualities: cheap, abundant, well distributed. Its only drawback is that it emits a lot of CO_2. That is why it is so important to be able to capture and store CO_2. Admittedly that raises technical and economic problems that have not yet been totally resolved and no doubt also problems of social acceptability that governments should be concerning themselves with already. But we simply must succeed, for if we do not, the planet will have many difficult days ahead. But we must also not over-dramatise the risks: CO_2 is not a toxic product. It is naturally present in abundance in the atmosphere and below-ground.

A.S. The IPCC devoted a special report to CCS, and estimates that between 15% and 55% of the effort needed to stabilise our emissions could come from such a strategy. The planet has a very large geological storage capacity, somewhere in the region of 2000 Gt (billion tonnes) of carbon dioxide! The consensus of opinion among scientists is that this gas could be stored in liquid form for tens of thousands of years before re-entering the atmosphere. But it is important to establish basic standards and secure procedures: energy producers risk not investing in this technology if they are legally liable in the event of gas escapes. The least expensive option would be to supply this technology to countries such as China where it can be incorporated in newly constructed plants rather than equipping existing plants.

Could the system of emission permits finance CCS? More generally, do you favour this system?

V.S. The system of emission permits is both ethically unacceptable and economically inappropriate. It is unacceptable because ultimately it is a system that rewards the polluter – whereas since the Rio summit the international community has adopted the principle that the polluter pays. That said, all kinds of convoluted arrangements are being introduced in connection with this polluter pays principle, in particular the so-called clean development mechanism (CDM). In the name of this system, we are generating a vast amount of polluting activities in China and India, congratulating ourselves on having cut their emissions by 10% while ignoring the 100% clean options! In India, the so-called *sponge steel* plants can be financed through CDMs despite being ecologically and socially disastrous. Emission permits are also an inappropriate system as it is founded on an industrial paradigm, making it incapable of taking into account the needs of traditional systems based on renewable energies – thereby ignoring totally the needs of the poor of this world.

C.M. What is needed to develop CCS is to allocate a cost to the carbon emitted into the atmosphere so that it becomes more economical to store it. This cost could be generated through a tax, a regulatory obligation, or an emission permit charge. The latter seems to me to be by far the best solution as it makes it possible to implement solutions at a lower cost. I am quite optimistic about its future: the European experience has been very interesting. It was criticised, but Europe had all the teething problems to deal with. There will be improvements and I note that more and more countries are expressing an interest. We can expect a major expansion of this system over the coming years, even if it will never be universal and perfect, and will have to make allowances for the particular cases of certain countries or industrial sectors.

A.S. There is no doubt that an intelligently designed emission permit market could stimulate carbon storage and, more generally, stimulate more efficient carbon usage. It will be for the politicians to decide whether such a system must be put into place and on possible special arrangements for poor countries. But we must not forget that, in many countries, the challenge is to bring electricity to rural populations despite the absence of a distribution grid – in which case solutions such as solar energy or wind power can prove both effective and cheap.

What should we think about biofuels, about which so much has been written?

V.S. Most of the world's poor use biomass as an energy source – understood as such, the notion of biofuel does not pose a problem. The problem is the transformation of vegetal matter into ethanol and biodiesel using industrial processes. First, because more and more studies are showing that the production of these agrifuels consumes more energy than it saves. But also and most importantly, because by trying to meet the needs of an "all fossil" economy by diverting agricultural land from growing food, we are generating a major crisis among the poorest. In India, under a recent government plan, 11 million hectares are to be planted with *jatropha* to produce biofuels. These crops are often planted on common land from which the peasant farmers are evicted, often by force. In practice, the needs of the poorest are denied so that the rich can continue to drive their cars.

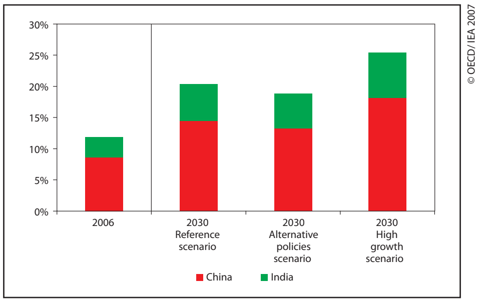
C.M. The IEA has long been saying that many fuels placed on the market are in fact more damaging than useful. The idea that, if we want to use biofuels, they must be produced in one's own country is absurd: Europe's cost conditions and climate make these fuels too expensive and cause them to emit too much CO_2. I fear that the EU's targets will prove difficult to meet in a sustainable manner. In fact, the best solution is no doubt to simply import ethanol from Brazil where it can be produced better and at a lower cost, while awaiting the second generation of fuels based on wood or whole plants.

A.S. It is vital for sustainability criteria to be developed and applied to biofuel production. It would not be right to fell tropical forests for ethanol or biodiesel production to comply with new European or North American standards. Or for agricultural land to be used. What is more, if it proves impossible to convince consumers that such production is ecologically compatible, it could all backfire. That said, biofuels could be a means of meeting part of the climate challenge while at the same supplying farmers in the developed and developing countries with new sources of revenue. Brazil says it can increase its ethanol production without any additional deforestation and indeed this country has reduced its deforestation by 50% over the past three or four years despite the growth in biofuels. So it is possible.

The energy system of the emerging countries is expanding very rapidly at present. Is there any chance it will take the route to sustainability?

V.S. The forces that are pulling the energy development of our countries (India, etc. – editor's note) in non-sustainable directions are the same as the forces that drove developed countries towards total hydrocarbon dependency. These forces, notably *agribusiness* or the motor industry, are now looking at expanding their markets in countries such as India. A "people's car" is to be launched here in India for example. It will cost US$2 500. But at that price it is not for the "people" at all, as just 5% of Indians can afford that! And the factory where it will be made as well as the steelworks that will supply it are based on land expropriated from farmers, often firing them in the process. And then the port from which the spare parts will arrive infringes on a mangrove that provides a natural protection against cyclones for the population. Let me give you another example: in India as in Europe and the United States, all subsidies go to industrial agriculture that consumes 10 times as much energy as biological agriculture. In fact, 95% of Indians do not want this energy system, they simply want to live – and that is something that only sustainable systems can provide.

C.M. As to China, there is a very strong desire to take this problem into account and I sense that it is ready to make a major effort to develop renewable energies, CCS and nuclear energy – even if everything will be partly dependent on negotiations over the next two years. China is already taking measures to improve energy efficiency. It is, for example, the country with the highest penetration of low-energy light bulbs in the world. For the automobile industry too, standards are based on European standards, with a two-year time lag. In this area the Chinese are much more advanced than the Americans! It will no doubt be more difficult for the other emerging countries as their policy is more chaotic than China's. But we must not lose hope because if we fail global warming threatens to exceed the IPCC forecasts and the costs of adapting to the changes will be truly exorbitant.



Oil needs of China and India according to the scenarios

A.S. There are some positive signs. China is often criticised for building a new coal-powered plant every week, but in fact these are often to replace existing plants with new ones thal are more efficient. South Africa and Brazil now use sustainability indicators and, in terms of renewable energies, two of the world's biggest companies are in China and India. But there is clearly an urgent need to accelerate the transfer of technologies to the developing countries. It is worth pointing out in passing that the Bali roadmap, which will serve as a basis for future climate talks, makes explicit reference to this. Then there is the need to speed up research: during the last oil crisis, in the late 1970s, a billion US dollars was invested in research on solar energy, resulting in a 50% increase in the efficiency of photovoltaic energy!

Do you believe nuclear energy can help us make the energy transition?

V.S. One sometimes has the impression that since global warming was discovered any form of energy that doesn't emit CO_2 has become "sustainable". Yet this is certainly not true of nuclear energy that is dangerous and generates huge quantities of toxic waste. Not even hydroelectricity is always sustainable. In India there is a powerful popular opposition movement to the building of large dams that – like the Three Gorges Dam in China – destroy rivers, generate landslides and pose an industrial risk. Dams have already displaced 50 million Indians! In countries like India, energies ● ● ●

***Big Island Fuel Crops* Project.** Biofuel research on jatropha, carried out in Hawaii by South Point Propagation, in cooperation with the *Hawaii Agricultural Research Center*, University of Hawaii Hilo and the *Hawaii Biodiesel Consortium*.

that consume capital are not really suited. What we must do is regenerate local renewable energy systems, animal energy, biomass, and the biogas that Gandhi already promoted on a large scale in his day.

C.M. Nuclear energy is absolutely essential. I do not see how one can seriously envisage sustainable development without nuclear energy contributing a share of the global energy supply. Unfortunately this share is in danger of falling during the next 20 years because many power plants will reach the end of their lives and they will not all be replaced. It seems to me there is a certain contradiction in seeking, like Germany, to cut CO_2 emissions, not be too dependent on Russian gas, and abandon nuclear energy! On the other hand, I do not believe we should favour the development of nuclear energy in countries that do not have a competent and fully independent safety authority. By that I mean a body with the authority to shut down a dangerous plant despite objections from the head of state.

A.S. It remains to be seen. Nuclear brings the risk of proliferation, a terrorist risk and geopolitical tensions that are already visible. In economic terms, if the costs of building and dismantling the nuclear plants and storing the waste are taken into account, it is then by no means certain that nuclear energy does not prove more costly in the long term than major investment in renewable energies.

Is it possible to move towards sustainable development without reducing our level of consumption or even question the notion of growth, at least in the rich nations? Is our economic system capable of such a development?

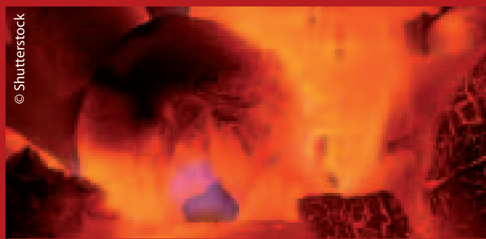
V.S. I do not believe that the market economy will be able to assure our future without a set of political regulations and support for non-intensive energy production systems. If the transition to tomorrow's world is made democratically, through debate in an informed context, then it can result in a fairer society, with increased well-being. On the other hand, if a powerful elite continues to impose unsustainable options so as to maintain a system that is ultimately doomed, while denying the poor their share of resources, then we will see an erosion and destruction of democracy, increased violence, and genuine social disintegration. A dominant, centralised model dictated by a handful of large companies, symbolised by monoculture and uniformity, must be replaced by a model based on decentralisation and diversity. But for that we also need an ethical transition. What does it mean to live a human life to the full? The market has no answer to that question; that is for society to answer.

C.M. We are certainly going to have to implement some profound changes. In our use of energy, fortunately we are a long way from having exhausted all the potential for productivity gains.

There are also some revolutions to be made in transport: perhaps the electric vehicle, perhaps alternative approaches to combining individual and public transport. In particular, we are going to have to rethink the link between problems of town planning and energy efficiency. As to growth, I would say that in future we must be content with very low growth in our countries, of between 1% and 3%. Clearly we are not going to see the kind of growth we had in the post-war years. But I do not see how we can explain to the emerging countries that they must limit their growth when their per capital wealth is a fifth or even a tenth of that of people in the West. No doubt we will have to change the way we calculate growth so as to better take account of its negative aspects, but I believe that the aspiration of having more goods, more wealth and better health and education is going to last for a long time yet. And it is possible to meet these aspirations while consuming much less energy.

A.S. The issue is not to reduce our economic activity but to make more intelligent use of our resources. From fishing to energy production, to date our development has wasted resources in a way that is clearly not sustainable. But there are some positive developments. A recent United Nations Environment Programme (UNEP) report estimates that investment in renewable energies such as wind power or solar energy now stand at US$100 billion a year or 18% of total energy investments. The financial services sector is also showing a growing interest in companies committed to sustainable development. More than 230 institutional investors representing several tens of thousands of billion US dollars now support the "*Principles for a Responsible Investment*" put into place by Kofi Annan in 2006. This sends a clear signal to the markets, a signal that social, environmental and governance conditions must become major concerns for the economy and investment. In other words, the way we do business is changing – partly because the markets and the consumers are demanding this transition.

Yves Sciama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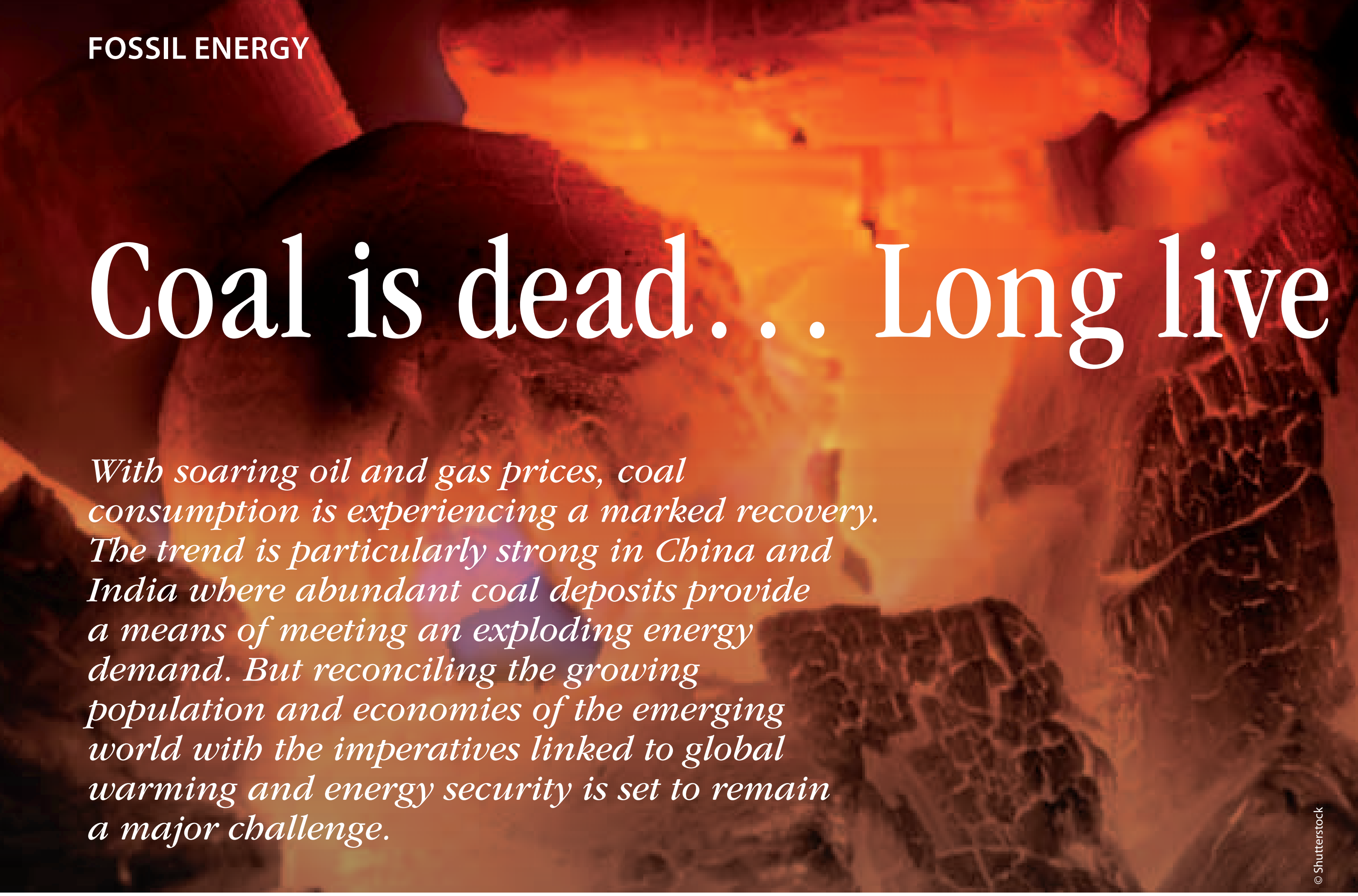
Prolonging the agony

When will we reach the world peak oil? This is the point at which the annual production of oil will peak before decreasing, indicating that half the world's reserves have been depleted. The experts are lost in conjecture: 2006? 2015? No matter because, according to another view, peak oil will coincide with the first socioeconomic and geopolitical upheavals caused by the growing shortage of black gold.

It is already happening. Now all we need to do is to make the reserves last until renewable energies make good their promise, while at the same time satisfying the exponential demand from emerging countries.

And meanwhile hunting down climate enemy number one: greenhouse gases. So the search for ideas is on. In industrialised countries, one idea is to improve energy efficiency. China and India are scouring the depths of their coal seams. Everywhere we can, we are capturing and storing greenhouse gases and making polluters pay for the privilege.



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Coal is dead. . . Long live

With soaring oil and gas prices, coal consumption is experiencing a marked recovery. The trend is particularly strong in China and India where abundant coal deposits provide a means of meeting an exploding energy demand. But reconciling the growing population and economies of the emerging world with the imperatives linked to global warming and energy security is set to remain a major challenge.

According to the reference scenario set out in the *World Energy Outlook 2007* published by the *International Energy Agency (IEA)* – focusing largely on China and India – global coal consumption will increase by 74% between 2004 and 2030. Global reserves currently stand at 998 billion tonnes, which is enough to meet the planet's energy demands for the next 160 years. Although coal is mined in over 100 countries on every continent except Antarctica, two-thirds of exploitable resources lie in the sub-soil of four countries. The United States has the largest stock, with 27% of the world's reserves, followed by Russia (17%), China (13%) and India (10%). In 2004, 66% of world production came from these four countries and two-thirds of the 5.9 billion tonnes of coal produced in 2005 was destined for electricity generation.

The exploding energy demand

This situation is very fortunate for India and China, which are in urgent need of energy to develop their industry and electricity grid. The IEA expects the number of people needing electricity in India to increase from 62% to 96% of the population between 2005 and 2030. This means India will have to triple its production capacity. "According to forecasts, 700 GW will have to be added to the Indian network by 2030, 60% of which will be generated using coal," says N.N. Gautam, a former expert attached to India's Ministry for Coal. China's energy targets are even more impressive: no less than 1 300 GW – equivalent to the total energy capacity of the United States! – will have to be added to the grid during this same period to satisfy consumer demand. Coal-fired plants will contribute 38%.

While 70% of India's coal demand comes from electricity generation, almost half (45%) of Chinese demand comes from its fast-growing basic industries, especially iron and steel. China is also interested in coal with a view to producing synthetic oil. The *Shenhua Coal Liquefaction Corporation* has just completed construction work in Mongolia on China's very first coal liquefaction factory. Inexpensive, immediately accessible and widely available worldwide, coal is coming to be seen as the most suitable energy option for meeting Chinese and Indian needs. These two countries will alone be responsible for as much as 72% of the growth in coal consumption between 2004 and 2030.

The pitfalls of the coal renaissance

This coal renaissance is nevertheless causing concerns. The quantity of CO_2 emitted during coal combustion is about 25% higher than that emitted by oil per unit of energy produced, and 50% higher than for gas. In 2004, coal was already the second most polluting energy source in terms of CO_2 emissions, accounting for about 39% of total emissions, and by 2010 it is expected to replace oil as the biggest polluter.

A vast deployment of CO_2 capture and storage systems (CCS) could limit the environmental impact of this return to coal, although the technology is still in its infancy and experts expect it will take another decade to perfect it. "In addition, present studies highlight a lack of storage solutions in India, thus complicating the installing of CCS. China does have some reservoirs but the storage potential in Asia remains low in comparison to the rest

coal?

Coal liquefaction: a sustainable solution?

Coal liquefaction – developed by Germany in the 1920s and widely used by the Nazis in World War Two – involves producing fuel for combustion engines from coal.

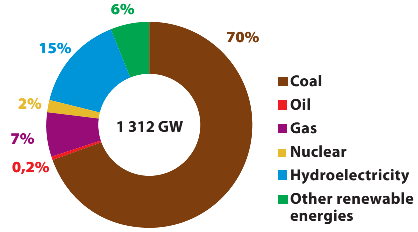
Indirect liquefaction is based on the Fischer-*Tropsch* (*F-T*) process and involves totally breaking down the coal's structure by gasification with oxygen and steam. This produces synthesis gas – syngas – that then reacts on an F-T catalyst to form liquid hydrocarbons.

Direct liquefaction is based on the *Bergius process*. This involves mixing with crushed coal a recycling solvent itself obtained from coal. The resultant coal paste is then heated to 450 °C in a hydrogen atmosphere at a pressure of between 13 900 and 20 900 kilopascals.

Revolutionary alchemy? That all depends on the efficiency of future techniques for capturing and storing CO_2 because, whether direct or indirect, liquefaction releases much more CO_2 than oil extraction and refining.

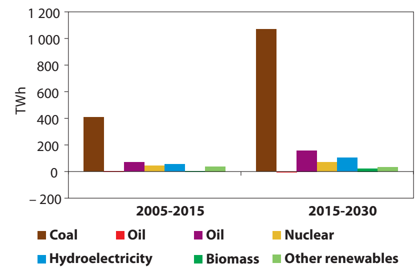
Forecasted increase in electricity production capacities in China

(IEA reference scenario 2005-2030)



Forecasted growth in fuel for electricity production in India

(IEA reference scenario 2005-2030)



of the world," believes Sankar Bhattacharya, CCS expert at the IEA.

"In accordance with the IEA recommendations for the short term, China and India are today concentrating on optimising the yield of certain existing coal-fired power plants and closing the most archaic plants that are too polluting," explains the expert. Subsequently, to reduce drastically greenhouse gas emissions in the medium term, the IEA recommends the large-scale installation of clean-coal technologies. Also, with a view to reducing dependency on a single and limited energy, it advocates diversifying energy sources by investing in the long term in nuclear and renewable energies.

A necessary technology transfer

China has already shown proof of goodwill, in particular by announcing a 20% reduction in energy consumption per unit of GDP by 2010 and making a determined effort to exploit its green energy potential. "China is set to invest over 10 billion US dollars in developing its renewable energy facilities in 2007, making it the world's second biggest investor in this sector after Germany," states a press release published at the end of 2007 on the *Worldwatch Institute* (1) site. However, emerging countries are demanding financial support and a greater technology transfer on the part of rich nations, a message clearly stated at the international climate conference in Bali last December. "The developing countries are not going to sacrifice their quality of life in the name of global warming," warned N.N. Gautam. "The developed world must therefore increase the transfer of technologies to the poor countries."

With its origins in the *European Coal and Steel Community* (*ECSC*), the European Union is also increasing its research on clean coal to counter its dependency on gas and oil imports. The ECSC treaty, which expired in 2002, has enabled the EU to cultivate a high-tech expertise, both in terms of energy efficiency and clean combustion, thanks to 50 years of pooling research on coal and steel. It is an expertise that, if shared, could prove extremely useful to the developing countries.

Research will clearly play a key role in harmonising economic growth, energy consumption and environmental protection at world level. It remains to be seen if and how politicians will coordinate the huge scientific effort needed to meet this formidable challenge. The choice is a crucial one as many experts declare that, in the context of a global energy shortage, what humanity is most lacking is not the resources or the technologies, but time.

Julie Van Rossom

(1) *China on pace to become global leader in renewable energy*, www.worldwatch.org, 14/11/2007.

i www.iea.org
www.worldenergyoutlook.org

Zero emission target

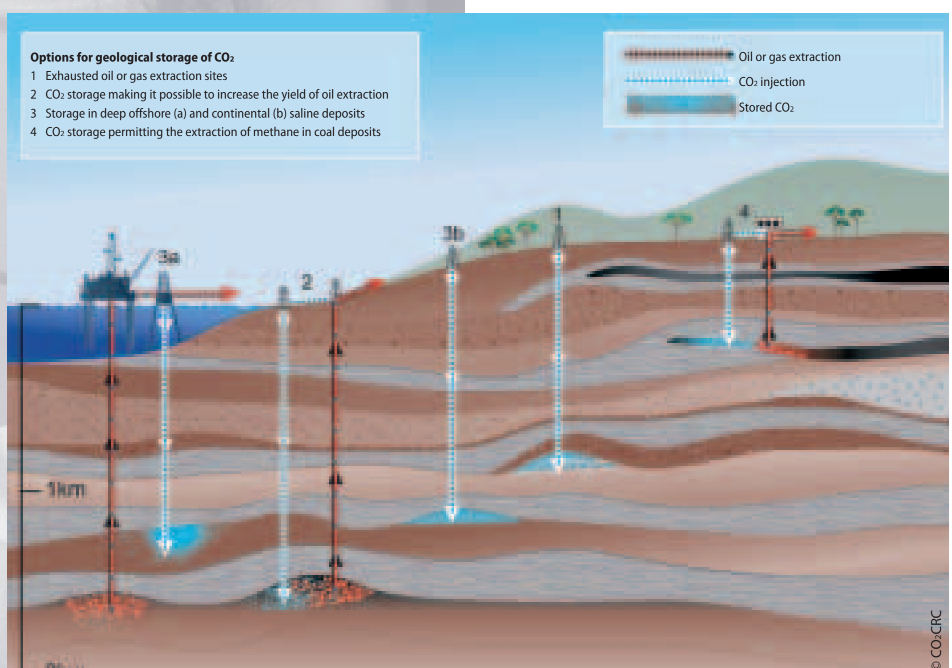
According to all the scenarios, natural gas and coal could supply the electricity and industry sectors with sufficient electricity for at least another 50 years. But hydrocarbons mean greenhouse gases, which in turn raises the question of carbon dioxide capture and storage, the energy cost of which remains much too high.

© CO_2CRC

Julianna Franco, researcher at Melbourne University (Australia) reading the results of experiments on membrane-based CO_2 extraction.

All of Europe's oil- and coal-fired electrical power plants equipped with a carbon capture and storage system (CCS). Is this a realistic prospect or pure fantasy? For the past three years the *Castor* (*CO_2 from capture to storage*) project has been looking at Europe's energy sector to test the feasibility of postcombustion capture systems and the accompanying CO_2 storage methods.

Postcombustion makes it possible to intercept the CO_2 within the smoke that is usually emitted into the atmosphere. "It has the advantage of being easily adaptable to traditional electrical power plants and as such is the capture system most suitable for short-term implementation," explains Pierre Le Thiez, *Castor* coordinator for the *French Oil Institute*. "The principle is simple. The smoke that escapes is processed inside a contactor that contains a solvent that binds with carbon



© CO_2CRC

dioxide. Once 'enriched' in this way, the solvent passes to a regenerator where it is heated to break the chemical links that bind it to the CO_2. The carbonic gas is then captured and the depleted solvent reinjected into the circuit."

The method has been tested in Esbjerg, Denmark, since March 2006 where a coal-fired plant fitted with a CCS system was introduced as part of the *Castor* project. This unique pilot project, the only one of its kind anywhere in the world, will make it possible to test and improve postcombustion. "Reduction of the capture costs, at present responsible for around two-thirds of the total cost of CCS, is crucially important. Because if the process of reducing CO_2 emissions proves as energy-hungry as the electricity generation itself, CCS clearly ceases to be of any interest."

The competitors: pre- and oxycombustion

Since 2000, a major research effort has also focused on two other capture options: precombustion and oxycombustion. These both offer possible potential in the longer term.

Precombustion, which captures the CO_2 upstream, adds steam or oxygen to the fuel so as to transform it into synthesis gas – syngas – made up of CO_2 and hydrogen. Once isolated, the hydrogen is used to generate electricity while the CO_2 is liquefied prior to storage. This constitutes a first step towards the hydrogen society. In Europe the research is being carried out by the *HypoGen* project – the counterpart to the US *FuturGen* project – that aims to build Europe's first electrical power plant equipped with precombustion CCS. The first phase of *HypoGen* is being implemented by the *Dynamis* (*Towards Hydrogen and Electricity Production with Carbon Dioxide Capture and Storage*) project which is looking at feasibility issues, seeking in particular to reduce capture costs by 50%. "Nothing is certain as yet, we still have to convince the creditors of the project's viability if they are to finance the construction of pilot plants," explains Nils Anders Røkke, *Dynamis* coordinator within *Sintef*, an independent Norwegian research institute. "Some technological problems continue to bar the route to this generation of clean energy production, in particular the fact that as yet there exists no turbine able to run on 100% hydrogen."

Much less advanced technologically than the two previous methods, oxycombustion makes it possible to generate an exhaust smoke with a very high CO_2 concentration. It is enough to burn the fuel in pure oxygen rather than air to obtain a smoke with more than 90% CO_2 concentration and which can then be captured directly as such. Nevertheless, the process remains too costly at present as it requires large quantities of energy to produce pure oxygen."

Burying the CO_2

"No capture without storage," is Nils Anders Røkke's judicious reminder. Indeed, there is no point capturing CO_2 if you don't know how to store it. "The problem is that it is impossible to test the viability of a process over hundreds if not thousands of years. So studies are concentrating on the analysis of natural geological sinks in which CO_2 has been imprisoned for millions of years, as well as on the observation and study of existing industrial storage systems. The data obtained is then extrapolated in the framework of these projects with the help of predictive computer models," explains Pierre Le Thiez.

Ocean sinks(1) and mineral sequestration(2) are today no longer regarded as viable storage solutions as they present too many disadvantages compared with geological storage. The latter involves injecting CO_2 into the intergranular space of porous and permeable rocks that are present in geological formations virtually all over the world. These deep sedimentary deposits sometimes extend over hundreds or even thousands of kilometres and are generally filled with salt water, which is why they are known as saline aquifers. They sometimes already contain CO_2 in their natural state, which led to the idea of injecting them with the gas. Experiments in this field have been carried out since 1996 by the Norwegian company *Statoil* in particular, at its Sleipner (Norway) site in the North Sea, and they have proved very convincing to date.

A profitable storage?

Saline aquifers can also include "trapping" structures that contain methane or oil. Storage can thus be optimised by injecting CO_2 into almost exhausted deposits, re-pressurising them and extracting the residual oil or natural gas. This method of "CO_2 injection assisted recovery" has been practiced by the oil industry for decades now and could also be used for unexploited coal deposits that are also candidates for carbon storage.

However, Pierre Le Thiez explains that these assisted recovery methods, whether from depleted deposits or unexploitable coal seams, are losing some of their interest. "Many of these reservoirs are too small and, in the case of oil or gas deposits, were very often penetrated in the past by a number of wells, raising the problem of impermeability. This is why I believe that saline aquifers are the most viable geological storage method."

Time is short for introducing systems for reducing CO_2 emissions, such as CCS. Electrical power plants today generate 40% of global emissions and CCS could also be applied to industries that use coal or gas as the principal fuels. It is a question of resources, believes Nils Anders Røkke: "The political recognition of global warming has catalysed a growing interest in CO_2 capture, resulting in increased financing for related research. But resources are still sadly lacking with which to perfect these technologies as quickly as is necessary." ●

J.V.R.

(1) The oceans are natural carbon sinks. But they seem to be saturated already by the atmospheric CO_2 that is also increasing their acidity.
(2) We are accelerating mineral carbonation, a natural process for the formation of carbonated rocks. But the technology remains very costly.

Castor
30 partners – 11 countries
(AT-DE-DK-ES-FR-EL-IT-NL-NO-SE-UK)
www.co2castor.com/QuickPlace/castor/Main.nsf/

Dynamis
32 partners – 12 countries
(AT-BG-CH-DE-DK-ES-FR-IT-NL-NO-SE-UK)
www.dynamis-hypogen.com

Doing more with less

The most direct weapon for combating Europe's dependency on hydrocarbon imports can be summed up in just two words: energy efficiency. The energy-thirsty construction sector in particular offers major scope for savings.

Consume better to consume less: that is Europe's new motto. As it tackles three key sectors – transport, industry and construction – it aims to reduce energy consumption by 20% by 2020. The European Commission's "*Action plan for energy efficiency*" identifies the construction sector as top priority, with it alone absorbing about 40% of the EU's energy. Housing accounts for about two-thirds of this percentage, with public buildings and business premises making up the rest.

What is more, for once this is a field in which private interests are largely favourable to public initiatives. "Unlike other sectors, and transport in particular, introducing energy-efficiency measures to buildings brings only benefits, in terms of reduced energy bills, increased comfort and job creation," stresses the *European Construction Industry Federation* in a memorandum (1).

Act locally, think globally

The eco-design of a building offers a twofold advantage. First, from an economic point of view it results in huge energy savings. "We can divide a building's energy consumption by eight and thus reduce consumption from 280 kW/h/m² to 35 or even 15 kW/h/m²," explains Claude Rener, Administrator with *Arc&Style*, a Belgian company that has specialised in eco-construction and eco-renovation for the past 25 years. Secondly, from an ecological point of view eco-construction concentrates on the global energy balance of a material and thus takes into account the energy used in its production as well as the energy savings it will permit when incorporated in a building. "We take into account the total impact of the material on the environment, from its creation to its destruction. It is an approach that also opens up a whole new recycling chain based on the recovery of grey energy (2) from materials," continues Rener.

Wood is particularly favoured in this new vision of construction. "This carbon reservoir can be used both as the frame and as insulation, in the form of wood fibre for example. It makes it possible to obtain a very low K coefficient (3), and thus to limit heat loss from the building. To offset wood's low thermal mass – its ability to store heat – it is combined with silico-calcareous materials that are less demanding on energy than earthenware bricks and better calibrated, which makes it possible to limit mortar use. Admittedly these bricks are a little less effective in terms of insulation but when reinforced with wood insulating sheets the energy results are nevertheless excellent."

This innovative approach also marks a return to the materials of the past. "Traditionally, wood has been favoured in the construction sector. Similarly, natural, earth-based coatings, straw, air-slaked lime, marble or casein powder are making a marked comeback after having been abandoned during the past 30 years or so," notes Rener. "When combined with modern methods – such as domotics that make it possible to automate a building, or heat pumps that will soon replace condensing boilers – these traditional materials help save vast amounts of energy."

The biggest challenge of course lies in renovating existing buildings, which are the most numerous and the least efficient. "All the technologies needed have already been developed and the issue now is to discover how to speed up their inclusion in everyday life," explains Andrew Warren, Adviser with the *European Alliance of Companies for Energy Efficiency in Buildings* (*EuroAce*). This is the goal of *the European Energy Performance of Buildings Directive* (*EPDB*), which entered into force in 2003 and introduces requirements in terms of the energy certification of buildings, a joint evaluation methodology, minimum performances for certain buildings and the training of experts to make regular inspections.

The inaction of Member States

By adopting such measures Europe would already be able to reduce its energy consumption by 11%. Yet despite such promising potential, the Member States seem torn between the political commitments given at European level and the actual implementation of the measures laid down in the EPDB. At the end of February 2007, infringement procedures were instigated against 19 countries that had failed to submit an action plan setting out national measures acting on the Directive.

"It was negotiated by the energy ministers but has to be applied at national level by the construction and buildings ministers, hence the problem of synchronisation certainly explains this delay on the part of Member States," says Andrew Warren. "This situation is further aggravated by the fact that building policy is fragmented inside the Member States themselves, with responsibility lying at regional level. Also, only new buildings and buildings of more than 1 000 m² that undergo major renovation are subject to energy performance obligations. The present shortage of experts is also delaying the system of certification that is supposed to draw up an inventory and identify actions to be taken for each building owner. It must also be said that this is the first energy efficiency measure to really tackle buildings globally so it is perhaps not surprising that implementation is taking rather long."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How to make buildings less energy thirsty? By insulating, opting for wood or solar panels. The "blue flame" (*Laboratoire d'Études Thermiques* – CNRS) is a visualisation of internal air movements as an aid to an understanding of turbulence to control heat transfer while minimising energy consumption.

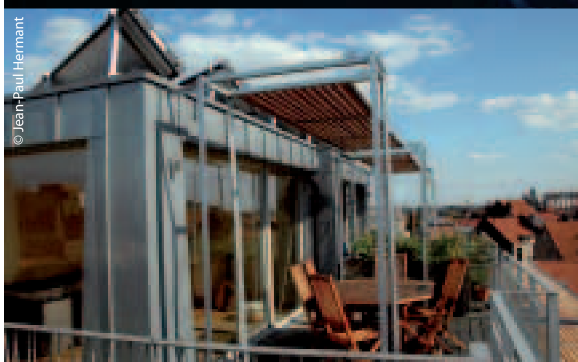
"Fortunately," says Claude Rener, "whereas we were preaching in the desert for 20 years, we have now seen a major shift in public thinking since 2000, and also among politicians who – at least in Belgium, the Netherlands, France and Germany – are making strenuous efforts to put into place financial incentives."

J.V.R.

(1) *FIEC Memorandum, The impact of buildings on climate change - FIEC's suggestions for raising the energy performance of buildings, 6/12/2007.*
(2) The quantity of energy needed for the production of industrial materials or products.
(3) Heat insulation coefficient of a material constituting a wall or a building (not to be confused with the lambda) – the lower the figure the better the insulating performance.

ec.europa.eu/energy/demand/
clusters.wallonie.be/ecoconstruction/fr/

Maison des Cyclistes in Ixelles (Brussels – BE). Frame in FSC (Forest Stewardship Council)-certified wood, thermal solar panels, geothermics, double glazing and insulation, eco-materials, vegetal roof.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Some European projects

What to do while waiting for Member States to transpose European resolutions? *Intelligent energy for Europe*, a vast programme launched in 2003 and now financed under the *Framework Programme for Competition and Innovation*, already supports many projects designed to promote the development of green energies and improve energy efficiency.

- *EuroTopten* is a website where you can compare the energy efficiency of various products available on the market. It consists of 10 sites for 10 Member States (FR, AT, BE, HO, IT, PO, HE, NL, FI, CZ).
- The *ECO N'HOME* project offers 1 000 European households a free energy audit of their home and travel practices. The data obtained are then used to draw up a guide to best practice in this field.
- *BOILEFF* aims to optimise the use of boilers and water heaters. Responsible for most of the energy consumed in European buildings, these appliances are often improperly used or badly maintained.
- *REMODECE* is seeking to compile a database and computer programme of the various characteristics of residential electricity consumption in the EU countries.
- The new EU Member States are much less advanced in terms of energy performance.

The *CEECAP* project is seeking to identify the best way of introducing energy labels for devices in Eastern and Central Europe.

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Trading the right to pollute

2008 sees the launch of the international system for trading in emission rights as laid down in the Kyoto Protocol. Since 2005, it is Europe that has taken the lead. But how exactly does this market operate and, most importantly, can it prove effective?

Kyoto commits the Member States to reducing their greenhouse gas (GHG) emissions by adopting the appropriate measures. To ensure that the policy does not to compromise economic development, three 'flexibility' mechanisms have been introduced. The *International emissions trading market* tackles greenhouse gases emitted in industrialised countries and the two other mechanisms (1) – emissions in the developing and transition countries.

These mechanisms take their inspiration from tried and tested solutions, such as in the United States for SO_2 emissions. The best known is the *cap and trade* system that sets a limit or *cap* on the emission entitlement of each 'polluter' who therefore has to reduce emissions and bear the related cost. If the operation proves too costly for company A, that company can then purchase 'emission rights' from company B for which the cost is lower, thus effectively financing the latter's emission reductions. Hence the notion of *trading* in emission rights. Everybody benefits, including the atmosphere.

A and B do not interact directly, however, but negotiate emission rights through access to a regulated exchange or market. The starting limits must also be realistic and then subsequently lowered to make emission rights an increasingly scarce commodity and thus increasingly costly. "The threshold price from which the system permits emission reductions varies depending on the field of activity," explains Claire Dufour, Product Manager at *BlueNext*, the French exchange market. "The main aim of *cap and trade* systems is to allow for variations in the costs linked to emission reductions from one sector to another."

A bad start

For the *International emissions trading market*, it is the Kyoto Protocol that sets the limits (expressed as quotas) of the signatory states while the *United Nations Framework Convention on Climate Change* (*UNFCCC*) must ensure that the system works effectively. For its part, the European Union has taken the lead by introducing, between 2005 and 2007, Phase 1 of its own market, the *EU Emission Trading Scheme* (*EU ETS*). It is here that emission rights known as the *European Union Allowance* (*EUA*) are traded. For the ceilings, each country submits a "national quota allocation plan" for the European Commission's approval, this providing a breakdown of its quota per sector. (3).

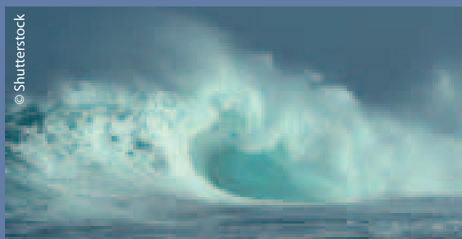
But of the 2.2 billion tonnes of CO_2 allocated for the EU, "only" 2 billion were rejected. The ceiling set was too high and consequently met without effort, the phase 1 EUA rate plummeting from around €25 to €0.03. The issuing right proved much too cheap to motivate companies to reduce their emissions.

Should we leave it to the Member States to draw up allocation plans? Claire Dufour seeks to be optimistic: "The Commission is becoming stricter. Nearly all the Member States had to revise the thresholds they proposed for Phase 2 of the EU ETS (2008–13). The EU's global threshold, although widened overall, was cut for $C0_2$ to 2.082 billion tonnes – 1.974 billion for the Phase 1 country installations – which has already increased the price by between €20 and €25 for Phase 2. The Commission's right of consultation will certainly guarantee the system's viability."

Delphine d'Hoop

(1) The Clean Development Mechanism (CDM) enables industrialised countries and their businesses to achieve their goals by financing projects to reduce emissions in the developing countries. Joint Implementation (JI) is a similar device for investments in countries in transition such as those of Eastern Europe and Russia.
(2) The terms "permits", "credits", "quotas", "units", etc. are all found depending on the systems. For GHGs these represent the equivalent of one tonne of CO_2.
(3) The EU ETS is for energy, ferrous metals, non-metallic minerals, pulp and paper only.

i ec.europa.eu/environment/climat/emission.htm
www.eurocarbone.com
www.bluenext.eu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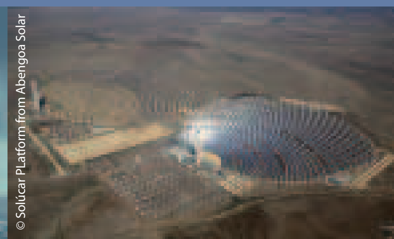
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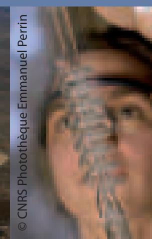
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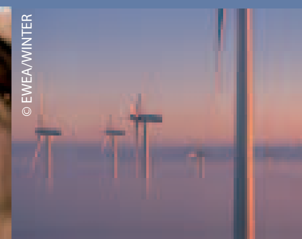
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Renewables, at last

The burning and brightness of the Sun, the heat of the Earth, the force of wind, the might of water, the bounty of plants. All are infinite or continually regenerated energies on which we are pinning our hopes. So great is the obsession with renewable energies that a fresh surge of creativity seems to be inspiring government and private research everywhere. Laboratories are teaming with new ideas: solar thermal energy, photovoltaics, geothermics, wind power, hydroelectricity, biomass.

Although at times these energies compete, we now know that they will all need to be harnessed and our overly rigid power distribution systems will need to be adapted to supply them. So there is already speculation about the ingredients and mix of our future energy cocktail. Of course there's many a slip twixt cup and lip, especially when enthusiasm turns into a mindless fad, as has happened with biofuels – a solution that is showing its limitations.

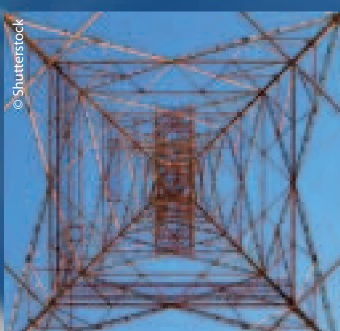
But learning is a process of trial and error. And never have we needed research so much.

Rethinking the European grid

For a number of years now, European research has been trying to overcome a major challenge: how to modernise distribution networks that are sometimes 50 years old by incorporating new production units that are dependent on the whims of the sun or wind.

Today, electricity distribution generally has a centralised and vertical structure. Companies produce electricity at a few powerful production units, subsequently feeding the supply into a distribution network or grid. Consumers then passively receive the electricity used in line with their needs. This is a one-way flow in which the last element in the chain (the consumer) has no control, beyond that of making certain choices, of supplier for example. It is a system designed to operate on a large scale, either regional or national.

But things are starting to change. The European Union is seeking to point the system in a new direction, by supporting research efforts in this field. The timing is particularly opportune. Existing distribution systems, built about 50 years ago, are becoming obsolete and over the coming years will have to be progressively replaced. There is every reason to do so as efficiently as possible, by allowing for the requirements of our age.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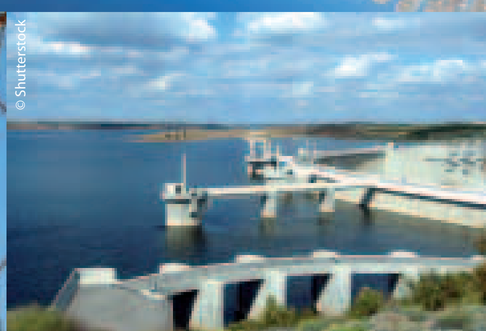
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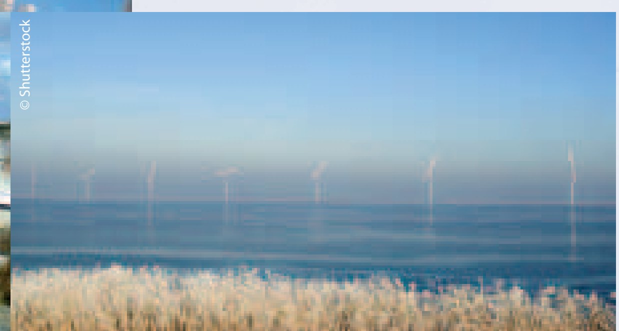
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The paradox of renewables

In response to climate change, recent years have brought a growth in renewable energies and with it the problem of incorporating them in the design of existing distribution networks. “This is in fact a problem that existed prior to the industrial revolution of the 19th century, when we relied on nature alone to supply our needs,” remarks Jacques Deuse, Technical Manager with the *EU-DEEP* (*EUropean Distributed EnErgy Partnership*) integrated research project on distribution networks.

"With renewables, we are returning to dependency on nature. Wind and sun in particular are not necessarily available when the consumer needs them. In our regions, for example, it is in winter that we need a lot of electricity but it is in winter that there is the least sun…"

As it is not easy to store electricity, production must match consumption as closely as possible. This is why it is such a challenge for the network regulators to incorporate such a variable and unpredictable factor as electricity generated by solar and wind renewables. While wind turbines generating flat out in high winds will create a production surplus if demand is insufficient, it is not possible to shut down production of traditional coal or gas plants as they take too long to start up again if the wind suddenly drops. They are rather switched to a low-generating regime, ready to fire up again when needed. But it is in this mode that power plants fuelled by hydrocarbons generally emit the most greenhouse gas per unit supplied. Thus the paradoxical situation whereby giving priority to wind-generated electricity can result in a more polluting production.

A radical rethink of distribution networks thus seems essential. As to the solution, this is what the dozens of scientists from research centres, universities and private and public companies working on the largely EU-financed *SmartGrids* platform and *EU-DEEP* research project are seeking to come up with.

SmartGrids in the long term

Two key ideas underpin future distribution networks or electricity grids. The first is a better interconnection of existing networks to create a vast European grid. The bigger the network the greater the likelihood of being able to balance production and demand. If there is no wind to turn the turbines in Denmark, for example, the electricity shortage could be offset by solar-powered plants in Spain.

The other idea is to permit a two-way flow. A myriad of small local networks powered by individual wind turbines or photovoltaic panels on the roofs of houses could ultimately be harnessed as part of the international grid. When the mini-networks are not producing enough electricity for local consumption, the main grid could step in. If the opposite is the case, they could sell the surplus to the main grid. This design would ensure a two-way flow in which the consumer would to a degree be an active producer.

The *SmartGrids* researchers claim a number of advantages for their system. Renewable energies could easily be included in the mini-networks as well as the main grid, without posing any problems in terms of low voltage or intermittence. This would result in decreased CO_2 emissions. Costs for the consumers would also fall as they would produce a part of their own electricity and could even sell any surplus.

EU-DEEP in the short term

Such infrastructure cannot be created overnight, however, and much remains to be done before being able to reap its full benefits on a large scale. It requires extremely high performance connection systems as well as highly developed logistics. As a result, it is a vision that is only feasible in the relatively long term.

"On the other hand, the *EU-DEEP* project is deeply rooted in the here and now," explains Jacques Deuse. "It is not a question of making a clean sweep and starting again from scratch. We want to improve existing skills and infrastructures to meet the needs of today, tomorrow and the day after tomorrow. We are proposing a new design for distribution networks that permits a flexible integration of distributed electricity production into the grid. Within this system the consumer and the producer are treated separately. The client is supplied by the electricity supplier, but through this supplier or another entity the consumer can also sell their own local production. As to the distribution system, this must be conceived of on a Europe-wide scale so as to be best able to deal with the issue of the intermittent supply of wind- and solar-generated electricity."

Matthieu Lethé

Large-scale storage

While awaiting the large-scale implementation of new distribution networks, there remains the problem of the intermittent nature of the most renewable energies.

One solution would be to store surplus electricity production at times when consumption is low and then reinject it into the network at times of peak consumption. The problem with this is that electricity is very difficult to store in large quantities. But for several decades now there have existed vast reservoirs of electricity: *Pumped Storage Plants*. These consist of two successive dams, with a major level difference between the two. In Europe, the largest of these plants is situated in the French Alps, at the Grand'Maison Dam. At times of peak consumption, when production units – whether traditional or renewable – are unable to meet demand, the water held in the upper basin is released into the lower basin to generate electricity, like a traditional dam. On the other hand, when the electricity produced exceeds demand, the surplus is used to activate powerful pumps that transfer the water back to the upper basin.

Pumped Storage Plants have the advantage of excellent performance: just one-fifth of the energy is lost in the flows. The drawback is that they take up too much space and require a mountain site.

SmartGrids
www.smartgrids.eu
EU-DEEP
39 partners – 15 countries (BE-ES-FR-UK-DE-PL-AU-SE-FI-CZ-HU-LV-GR-CY-TK)
www.eudeep.com

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From promises to

In Europe, transport is responsible for the biggest increase in greenhouse gas (GHG) emissions. This is a trend that a new European directive would like to reverse by having biofuels meet 10% of transport sector needs by 2020, as opposed to 2% at present. However, the use of biofuels is also raising many fears about the possible environmental and social impact. It is no doubt optimistic to believe that these concerns will be allayed by the second generation of biofuels.

Installing a glass fixed bed micro-reactor to evaluate catalysts with a view to developing new clean production methods.

© CNRS Photothèque/Emmanuel Perrin

It was the *Royal Society* (UK) that sounded the warning, in its January report entitled *Sustainable biofuels: prospects and challenges*. "Unless biofuel development is supported by appropriate policies and economic instruments that address these issues, then there is a risk that we may become locked into inefficient – and potentially environmentally harmful – biofuel supply chains." The House of Commons Environmental Audit Committee went even further in calling for a moratorium on biofuels. At the very time when the European Union is aiming for a 10% share of biofuels in the transport sector by 2020, many politicians, scientists and members of civil society are stressing the uncertain carbon footprint of biofuels, their environmental consequences and the higher food prices they are generating.

Emissions: no consensus

The GHG emission savings generated by biofuels depend very much on the parameters taken into account. Renton Righelato, President of the *World Land Trust*, and Dominick Spracklen of *Leeds University* (UK)[1] consider that the model used by the European Commission fails to take into account the indirect effects of converting land and forest for biofuels or the displacement of food crops outside Europe. These scientists believe that an area of forest stores between two and nine times the quantity of greenhouse gases as would be gained on the emissions side by using that same area to produce biofuels. "A 10% target would require the use of 38% of Europe's arable land, requiring the import of agricultural raw materials and leading to deforestation in other countries," adds Dominick Spracklen. But for Etienne Poitrat, Head of Biofuels at the *French Environment and Energy Management Agency – ADEME*[2], a significantly smaller land area could suffice – 14% for France, for example.

Paul Crutzen, an atmospheric chemist at the *Max-Planck-Institut* (Germany) and 1985 Nobel Prize winner for chemistry, estimates that the

doubts

amount of nitrogen in fertilizers that is converted into nitrous oxide (N_2O) – a greenhouse gas almost 300 times more powerful than CO_2 – is between 3% and 5% rather than the current estimate of 2%. Another example: the ADEME estimates the increased greenhouse gases resulting from ethanol produced from wheat to be 60%, while the scientists and industrialists at the Commission's *Joint Research Centre* (*JRC*) put this at somewhere between – -8% and + 80%. It is all a question of how one evaluates the share of refining co-products in the gains or the sources and quantities of energy needed for production.

Eat or drive?

In the EU today, 81% of land is given over to forests or crops and available fallow land represents no more than around 11% of cultivable land. However, achieving the 10% biofuel target would require the use of between 15% and 38% of the land, depending on the studies. There is thus a real risk that the growth of biofuels will result in significant damage to the environment, with the loss of ecosystems, intensive farming, soil degradation, deforestation and increased water consumption. "As long as markets do not correctly take the environment into account, there will be a major incentive to convert natural ecosystems into plantations for biofuels," writes the *OECD* in its 2007 report entitled *Biofuels: is the cure worse than the disease?*

The OECD also estimates that subsidies granted to biofuels have the effect of diverting land from food crops, thereby causing prices to rise. With a 40% increase in food prices in 2007, a 52% increase in wheat prices and a 70% increase in oilseed and vegetable oil prices (*Food and Agriculture Organization* – FAO – figures), the choice between fuel and food is becoming very pertinent. This is not as serious in the rich countries – where food prices rose by "just" 22% between 2000 and 2007 – as in the least developed countries where the price rise is a staggering 90%. Although biofuel production is not the sole cause of the rise, the *FAO* nevertheless cited it as one of the four causes identified.

A necessary new generation

The Commission is not insensitive to these criticisms and is seeking to reassure by guaranteeing that land considered to be "carbon sinks" or with a high degree of biodiversity will not be converted. It is also counting on the second generation of biofuels – although they are not expected until 2015 – to improve the poor ecological and human balance of the first generation. Although using wheat and maize to produce bioethanol or growing colza for biofuel is fuelling concerns, the use of plants not dedicated to food production is likely to allay them. There will be no more oil- or sugar-based plants needed as the second generation aims to transform lignocellulose directly into alcohol or hydrocarbons.

Consisting of 25% lignin, 50% cellulose and 25% hemicellulose, lignocellulose constitutes the greater part of the plant biomass found in wood, leaves, tree and shrub stems and all herbaceous species.

Biological conversion

It is possible to convert this plant matter into fuel biologically. As cellulose is a polymer formed of glucose chains, the biological method involves recovering these sugars and converting them into ethanol through a process of fermentation. Although man has been able to produce alcohol from sugar for thousands of years, separating the cellulose from plant fibre (representing between 9% and 17% of the cost of cellulosic ethanol) and then breaking it down to extract the glucose (between 20% and 33% of the cost) is not so easy. The European project – *New Improvements for Lignocellulosic Ethanol* (*NILE*) – aims, among other things, to find a good panel of enzymes with which to recover the glucose through enzymatic hydrolysis. Their team is interested in cellulases, enzymes present in mushrooms (*Trichoderma reesei*), bacteria or other organisms that feed on raw plant matter, with a view to selecting the best candidates, combining them and developing production frameworks for boosting yields.

Biological conversion is far from optimal and only uses cellulosic sugars, disregarding hemicellulosic pentoses, sugars for which we have not yet mastered the fermentation processes. The *NILE* project is seeking to increase the yield and speed of enzymatic hydrolysis and increase the amount of ethanol produced per unit of dry matter, which is currently between 12% and 16%. Project coordinator Frédéric Monot believes that "current research should improve the yield of enzymatic hydrolysis, open up new avenues for exploiting pentoses and make better use of lignin."

Thermal conversion

The other solution is to heat the plant matter under conditions of high pressure and low oxygen, thereby "breaking" the molecules to extract a gas that is a mixture of carbon monoxide and hydrogen. This gas is then transformed by catalysis using iron or cobalt to obtain a hydrocarbon wax that is then refined into synthetic fuel. Although improvements are necessary to pretreat the plant matter, limit the formation of impurities during gasification and then filter the gas, each element in the chain is operational today. The next step is to bring them all together within a production unit that is sufficiently profitable. The chain of collecting, transporting and storing the raw materials represents a considerable cost, with the difficulty lying in finding the critical industrial size that makes it possible to maximise production and minimise the distances travelled to collect the biomass.

With a yield currently estimated at 15% fuel per dry matter unit, the German Energy Agency estimates the production potential at 4 000 litres per hectare. This would enable Germany to meet 20% of its total fuel consumption. The European biofuel platform tempers this enthusiasm, however, stressing the need for vast investment to industrialise the process – investments that the technological and commercial risks do not encourage.

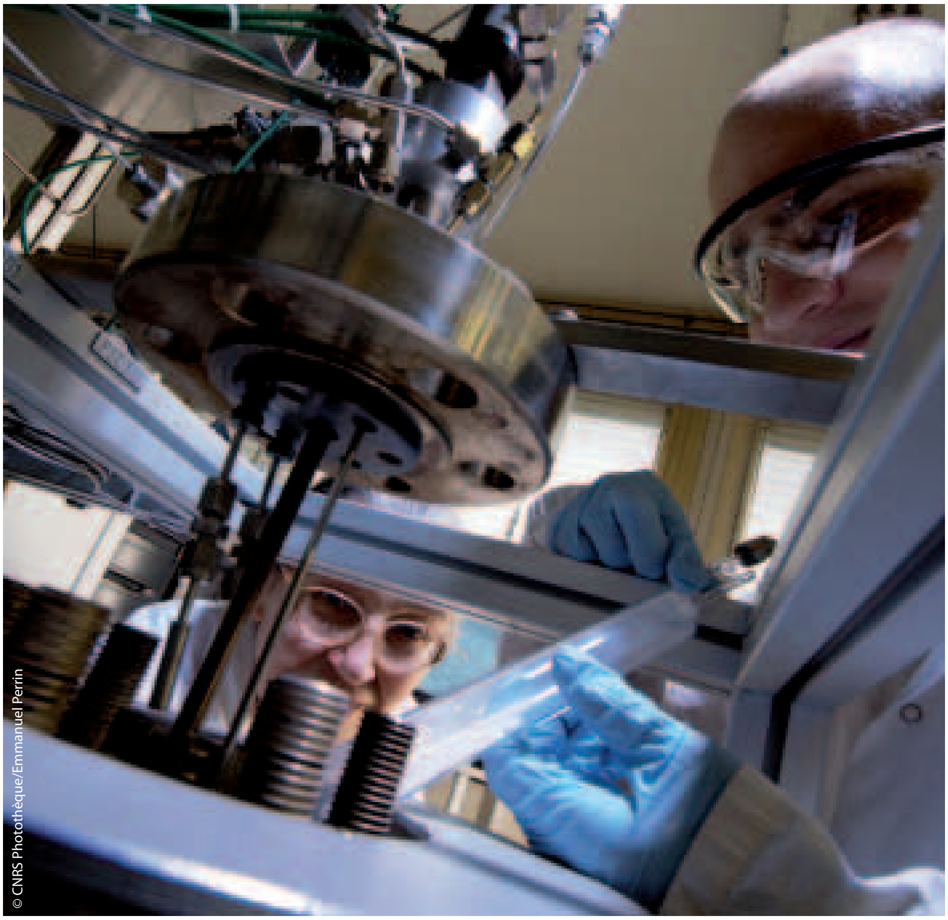
Not all is resolved

Today, Etienne Poitrat considers the biological route to be the most advanced, while stressing that "the demand for diesel being strong and with the biological process unable to meet this demand, there is certainly a role for thermal conversion." Yet these new techniques do not really ease the concerns raised by the first generation. Waste recovery

● ● ● is unlikely to meet more than 15–20% of biofuel needs and, despite a 35% forest cover in Europe, the quantity of remaining exploitable forest remains marginal. As to straw and other agricultural residue, their use for energy purposes is in direct competition with other sectors that use them, such as stock farming, crop farming and the paper industry. It is therefore impossible not to have land dedicated specifically to growing ligneous plants for biofuels.

Although high lignocellulose levels and a chemical structure that facilitates the extraction of sugars by biological means are essential criteria for these "energy plants", they must also be perennial, require little water input, be fast growing and cultivable on land unsuitable for growing food. The varieties in view are herbaceous plants such as *miscanthus* or *switchgrass* and trees such as the poplar, the willow or the locust tree. *EPOBIO*, a joint European and US research group, is studying these species to describe their varieties and identify their most interesting characteristics. Once the genetic sequences have been identified, the *EPOBIO* researchers will have to select, hybridise or genetically modify the different varieties to arrive at strains that are most suited to biofuel needs.

Moreover, even optimised to provide yield per hectare that is superior to that of the colza used for first generation biodiesel, these plants do not completely resolve the issue of the GHG balances for which it is becoming essential for the various stakeholders to agree on a calculation method accepted by all. European Environment Commissioner Stavros Dimas stresses that "the responses to social and environmental issues are precise and incorporated in the text". Of the arguments that fail to convince environmentalists, *Friends of the Earth* describe these responses as "particularly unsubstantial, offering no guarantee of sustainability."



Study of the catalytic reaction for green fuels. This device makes it possible to study the performances (activity, selectivity, life) of a solid catalyst.

Question of confidence

Is the EU awarding too much importance to these biofuels? Perhaps. But how to respond to the urgency of the need to reduce greenhouse gas emissions and the depletion of oil resources? Although Europeans may be sceptical about biofuels, that does not mean they are ready to leave their cars in the garage. It is thus up to the legislators to restore confidence by offering concrete guarantees on environmental protection, food price stability and the expected decrease in greenhouse gas emissions.

There is also another concern. If, as John Hontelez, Secretary General of the European Environmental Bureau, suggests, these measures are no more than a tool to "avoid applying genuine remedies to the growing role of transport in climate change," they could also attract funds and weaken other equally promising programmes. Electric vehicles, hydrogen cells, improved energy performance of vehicles or the reduction of transport needs may not offer short-term solutions, but they are perfectly in keeping with a true objective of sustainable development. As many experts state, biofuels are no more than a link in a chain and must not cause other avenues to remain unexplored. ●

François Rebufat

(1) *Carbon mitigation by biofuels or by saving and restoring forests?* Science Vol 317, August 2007.
(2) Energy and GHG balances of biofuels and conventional fuels – convergences and divergences of main studies, ADEME, July 2006.

NILE
21 partners – 11 countries
(FR-IT-FI-SE-DE-CH-BE-LV-UK-PT-IL)
www.nile-bioethanol.org

EPOBIO
12 partners – 9 countries
(FR-NE-SE-DE-CH-UK-GR-IT-US)
www.epobio.net/

Photovoltomania

The photovoltaic cell is poised for massive growth. According to the European Photovoltaic Technology Platform, it could cover up to 20% of the world's electricity needs by the year 2040. Increasingly efficient and affordable, the photovoltaic cell is well placed in the race for green energies.

Although the photovoltaic effect was first discovered by French physicist, Becquerel, in 1839, it was not until semiconductors were invented in the 1950s that an application was found for it. A photovoltaic (PV) cell is a device that generates direct current electricity from the energy of photons alone, with no mechanical or thermal input.

Two layers of a semiconductor material (more often than not silicon) are sandwiched between two electrodes. The upper layer (N), which is impregnated with an impurity with higher valency than silicon, such as phosphorus, initially has spare electrons. The lower layer (P), which is doped with an impurity with lower valency, such as boron, has a deficit. At the P-N junction, the electrons migrate from N to P until they achieve a balance, creating an electric field that prevents any subsequent transfer of charge. When light falls on the cell, the photons extract new electrons, so creating 'holes'. As these negative and positive charges are unable to cross the P-N junction, they are forced to travel through the electrodes, generating an electric current.

The energy efficiency of PV cells has increased from 8% in the 1980s to between 11% and 17% at present, although this is still not enough to guarantee the sector's profitability because of the high manufacturing cost. However, Germany has already succeeded in creating a market thanks to a highly proactive policy of incentives. In the space of eight years, the number of jobs in the photovoltaic sector has grown by a factor of 20, from 1 500 to 30 000. The sector's future depends heavily on research, both to improve performance (with planned energy efficiencies of 25–45% by the year 2030), and to reduce the costs of producing current modules.

This is the path that the European Commission has chosen to take with the *CrystalClear* project, which aims to make crystalline silicon cells more affordable. The behaviour of crystalline silicon, which is used in around 85% of solar modules, has been studied extensively. *CrystalClear* researchers are exploring two main avenues of enquiry. The first is to use new types of silicon, such as solar-grade silicon, which is less purified and hence cheaper. The second is to maximise the usable portion of silicon, mainly by reducing scrap and improving cell architecture.

"We are aiming to halve the price of silicon PV cells by overhauling their design entirely. One idea is to place both electrodes behind the cell, rather than on the front and rear as at present", explains Wim Sinke, *CrystalClear* project coordinator.

Reducing costs would also limit the environmental impact of production. Cutting down on the quantities of silicon used in PV cells also decreases the energy payback time (the amount of time a cell has to operate until it has produced the same amount of energy as was used to manufacture the cell), which is currently between one and two years. "So, reducing the costs goes hand in hand with reducing the environmental impact", concludes Wim Sinke.

Marie-Françoise Lefèvre

Other contenders…

The flexible thin-film CIGS solar cell uses an innovative semiconductor made from copper, indium, gallium and selenium. With a junction unlike the P-N junction, it achieves a conversion efficiency of close to 20%. Various types of thin-film solar cell are the main rivals to the current silicon modules.

The light and flexible plastic PV cell offers a conversion efficiency of 5% for a very low production cost. However, its sensitivity to oxygen and humidity makes it unsuitable for outdoor use, a drawback that researchers are endeavouring to resolve by encapsulating the cell.

The Graetzel solar cell works on the photosynthesis principle and is made up of nanocrystals of titanium dioxide (TiO_2) coated with organic dyes which sunlight causes to release electrons.

The conversion efficiency of the Graetzel solar cell exceeds 10% in the laboratory and its inventor, Professor Graetzel, has announced that his cell will be five times cheaper to manufacture than a silicon cell.

European Photovoltaic Technology Platform
www.eupvplatform.org/
CrystalClear
16 partners – 6 countries (BE-DE-ES-FR-NL-NO)
www.ipcrystalclear.info

From heat to megawatts

The Sun is responsible for 99.98 % of the thermal density at the Earth's surface and provides almost all our energy either directly or indirectly. It is an inexhaustible source of heat that can be converted into electricity during the day… and even at night.

The Sun was the sole source of energy at the Earth's beginnings, it triggers photosynthesis and its heat governs the rhythms of the water and wind cycles. Since humans first appeared on Earth, the Sun has governed the rhythm of their lives too, although people have learned to exploit it to meet their increasingly sophisticated needs. By 250 BC, the Greeks were already concentrating the Sun's rays on Roman ships to set them on fire. In the 18th century, Antoine Lavoisier managed to heat his solar furnace to 1 755 °C to melt platinum.

Now we are turning our attention to the Sun to generate electricity, among other things. By using light, photovoltaic cells are opening up a highly promising avenue of enquiry, but are not necessarily suited to mass energy production, enabling them to supplant traditional electric power plants. The other avenue is to exploit heat, direct solar radiation, in larger-scale concentrated solar power (CSP) facilities (1).

Even when they are erected in deserts or in areas with a lot of sunshine, CSP plants need to concentrate solar radiation to activate an efficient thermodynamic cycle for producing electricity. Mirrors track the path of the Sun and channel its rays onto a solar collector in which a heat transfer fluid circulates. This in turn feeds a heat-transfer medium (steam or gas such as air), activating a turbine that drives a generator. The principle is simple and the two power-plant variants for CSP – parabolic trough power plants and solar tower power plants – are yielding excellent results.

Power of concentration

Parabolic trough power plants are the most cost-effective and tried and tested means for concentrating solar power. They have achieved an efficiency level close to that of coal-fired electric power plants. Dozens of rows of curved reflectors, each containing a central tube filled with heat-transfer fluid, heat the fluid to a temperature of around 400 °C. This heat collector element (HCE) then feeds a conventional electrical unit.

Parabolic concentrators: CSP in miniature

An amazing module is being tested at the Almeria solar platform. The Euro-dish parabolic solar concentrator trains the Sun's rays onto a focal point where a Stirling engine transforms the heat into electricity. It is quick to assemble and not at all bulky. Energy efficiency exceeds 30 %, with a concentration factor of more than 2 000 suns and a temperature of 750 °C.

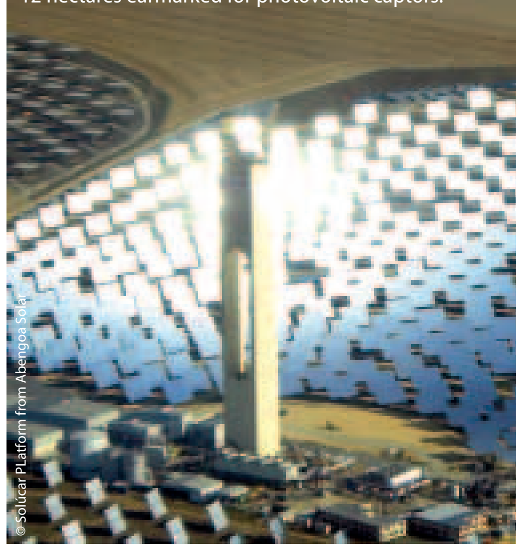
The dish targets the market for autonomous systems, to pump water for example. For the past 20 years, the concept has been developed in Arizona, mainly by Stirling Energy Systems (SES), which has integrated the dish into a 25 kW module. The module is aimed largely at remote areas where it is difficult to install and maintain CSP systems and to store energy. Another benefit is that the desired power output can be achieved by clustering several modules together. The technology can therefore supply networks with 25–50 MW, using a variable-sized power plant and a capacity for adjustment to achieve economies of scale.

If the current R&D collaboration between manufacturers proves successful, commercialisation is envisaged in 2–4 years from now, with excellent prospects for the future, especially in developing regions.

Solar dish by Stirling Energy System (USA).

© Randy J. Montoya, Sandia National Laboratories

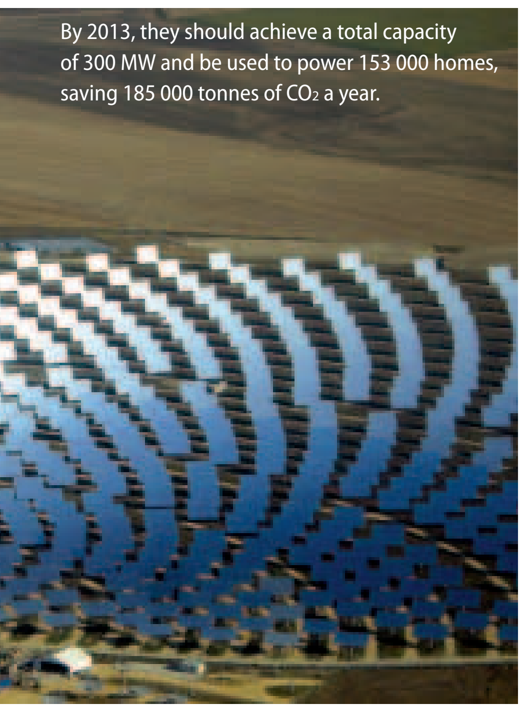
Sanlúcar La Mayor (near Seville in Spain), the site for Europe's largest CSP complex for electricity production, with its PS10 power station, the doubly powerful PS20 under construction and 12 hectares earmarked for photovoltaic captors.



© Solúcar PLatform from Abengoa Solar

Pilot projects for parabolic trough power plants sprang up in the United States in the 1980s and ended up being marketed. Solar electricity generating systems (SEGS) is a collection of nine plants with a total capacity of 354 MW currently in operation at Kramer Junction, in California's Mojave Desert. There are no industrial parabolic trough power plants in service in Europe. "The cost-effectiveness of parabolic trough power plants varies depending on the market and the cost of CO_2. Although parabolic trough technology is reliable, its prospects are limited because its concentration power is restricted to 100 suns, i.e. a maximum of 500°C", explains Gilles Flamant, Director of the Laboratory for Processes, Materials and Solar Energy (PROMES) at France's national scientific research centre (*Centre National de Recherche Scientifique – CNRS*).

As a result, interest has now turned to solar tower power plants, which also came to life in California in the 1980s, with Solar One, later redeveloped to make Solar Two, which have demonstrated the feasibility of power towers. In the case of solar tower power plants, an array of hundreds or thousands of mirrors – called heliostats – project the Sun's rays onto a single collector positioned at the top of a tower. "With a concentration factor of up to 1 000 suns, power towers have much greater development potential in terms of cost-effectiveness."



By 2013, they should achieve a total capacity of 300 MW and be used to power 153 000 homes, saving 185 000 tonnes of CO_2 a year.

Spain, where else?

In Europe, research began in the 1980s and has been concentrated mainly at the Almeria Solar Platform (PSA) in Spain's Tabernas Desert. The Spanish Research Centre for Energy, Environment and Technology (*Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas – CIEMAT*) is currently testing the CESA-1 solar tower power plant and a small solar power system (SSPS) at the Almeria site. Since 2004, the Spanish government has been providing a support framework for the initiative, by setting a guaranteed floor price per solar kWh.

All three of Europe's existing CSP projects are based in Spain. Each project has received European Union funding worth €5 million, which covers only part of the innovation costs. Additional funds are needed to carry out the conventional work, such as assembling the turbine. "Construction of Solar Tres has just begun, while that of Andasol should be completed shortly. The only project currently in commercial operation is the PS10 solar tower power plant, *Planta Solar 10*." (2)

Since 30 March 2007, the PS10 solar power tower has been injecting 11 MW of power into the electricity grid. 10 000 inhabitants consume the annual 21 GWh produced by the power plant. A 14-metre-wide collector placed at the summit of the 115-metre tower absorbs the heat from 624 heliostats into a fluid to produce steam. The four collector panels can concentrate an average power of 55 MW. "The idea is to validate the technology on an operational scale prior to the marketing stage. First the components will be developed in Europe (heliostats, collector) and then the plant's productivity has to be proven."

Storing heat

The problem with CSP is, of course, intermittent sunshine and the fact that generators cannot operate at night. At present the problem is resolved by storing the surplus energy accumulated during the day in large insulated tanks filled with molten salt. The PS10 solar tower power plant can store only 20 MWh, which allows it to offset overcast intervals. However, Solar Tres, which is expected to come into service in 2009, will have a storage capacity of 600 MWh, enabling it to produce its 15 MW continuously throughout summer and to operate for 15 hours after the sun has set, totalling close to 96 GWh annually, spread over 270 days.

In the case of parabolic trough power plants, in late July the Spanish group ACS Cobra and the German firm Solar Millennium will start marketing CSP electricity for the first time in Europe. Their parabolic trough facility, Andasol, will produce 50 MW, supplying nearly 180 GWh of energy every year. If the power supplied is any higher, stores dwindle faster. The 880 MWh stored during the day feed the power plant for only 7.5 hours once the Sun has set.

Dawn of the solar age

In 2005, CSP generated a mere 0.025% of the world's electricity. However, a slow but steady revolution is underway. In late 2007, Algerian Energy Minister, Chakib Khelil, laid the foundation stone of the Hassi R'mel hybrid solar-gas power plant. Shortly afterwards, the Chief Executive Officer of NEAL (New Energy Algeria) announced the construction of a 3 000-km, high voltage direct current (HVDC) connection between Adar and the German city of Aachen.

Solar thermal technologies are undeniably gaining ground. Simple, non-polluting and cheaper all the time, they can help to balance the world's energy relationships and to bring to the fore certain regions in the developing world.

Delphine d'Hoop

(1) Also called solar thermal power plants.
(2) All quotes are from Gilles Flamant.

PS10
4 partners, 2 countries (ES-DE)
www.solucar.es/

Solar Tres
4 partners, 3 countries (ES-FR-DE)
www.sener.es/

Andasol
6 partners, 3 countries (ES-DE-SL)
www.mileniosolar.com/

Other resources
www.TRECers.net
www.sollab.eu
www.solarpaces.org/

Rotors take to the high seas

Having exploited the North Sea's oil and gas resources since the 1960s, Europe has already acquired extensive experience with platforms at sea. It is currently enriching this experience with the DOWNVInD (Distant Offshore Windfarms with No Visual Impact in Deepwater) project, which focuses on an inexhaustible resource: powerful and steady offshore wind. The wind generators measure 126 metres in diameter… yet are almost invisible.

According to the latest estimates from the European Wind Energy Association (EWEA), by the end of 2007, one-quarter of the European Union's energy requirements could be met by installing wind generators across 5% of the North Sea's total surface area [1]. However, we are currently a long way from this proportion. Only five countries use offshore wind energy at present: Denmark, Ireland, the Netherlands, the United Kingdom and Sweden. At the end of 2006, their cumulative 900 MW represented only 3.3% of the European Union's wind-energy production. Today, their 25 offshore wind farms produce 1 100 megawatts. The conclusion is plain. Only a small portion of Europe's offshore wind energy resources are being exploited.

However, on 10 December 2007, amid a blaze of publicity the British government announced the launch of a national plan designed to supply 33 GW of electricity (or 33 000 MW – one-fifth of national requirements) to the country using offshore wind energy between now and 2020. Based on the use of current technology, this would require no less than 7 000 turbines to be built. The project's critics, complaining of the resulting disfigurement of the landscape, have made the somewhat misleading but hard-hitting calculation that this would mean seeing a wind generator every 800 metres all along Britain's coastline …

Obviously nobody seriously envisages distributing wind turbines all along the coast. On the contrary, the DOWNVInD project is seeking to make them as unobtrusive as possible. The aim of this €65 million project, of which €6 million is funded by the European Commission, is to set up and test offshore wind generators far out at sea in places where they are barely, if at all, visible from the shore.

Inspired civil engineering

The chosen site is 25 km out to sea in the Moray Firth off north-east Scotland. The new wind farm was given the quaint name of Beatrice Wind Farm, after the Beatrice oil rig only a few hundred metres away, which it has been supplying with one-third of the rig's electricity requirements since July 2007. The two wind generators that make up the wind farm, each with a capacity of 5 MW, are the first ever to be erected in waters around 50 metres deep. Up to now, such structures have been built only at depths of around 20 metres.

"Our chief problem has been to erect such a large infrastructure at sea so far from the coast", explains Allan MacAskill, Director of the DOWNVInD project. "Many parts were assembled onshore and transported out to sea to be set up at the correct site. In fact 'only'

© EWEA/WINTER

two trips were required: the first to transport the substructure jacket for anchoring the wind generator to the seabed and the second to transport the tower, turbine and blades previously assembled onshore."

This is quite a civil engineering feat, since the two wind turbine generators are immense. The 70-metre-tall substructure jacket, 20 metres of which will be submerged, weighs 750 tonnes. Although the tower-turbine-blade unit weighs less than 1 000 tonnes, it is rather bulky: with its 88-metre-high tower and 63-metre-long blades, the total diameter is 126 metres… After anchoring the substructure jacket, the engineers transported the wind generators in a vertical position, before setting them down on the substructure using giant floating cranes.

And the environment?

In parallel with the many studies conducted for the erection of these two turbines, the University of Aberdeen in Scotland has piloted a number of research programmes to assess the potential environmental impact of such wind generators both on the shores of the Moray Firth and out at sea. A maximum number of scenarios was considered in all project phases, ranging from onshore assembly to the operation of the turbines, including transporting, fixing, installing and maintaining the structures, dismantling them at the end of their life and even possible accidents and emergencies.

DOWNVinD has obviously left nothing to chance. It has made a census of the various animal and plant species living in the surrounding area, introduced measures to assess air and water quality, together with the visual, noise and electromagnetic impact, conducted surveys of the people living on the shores of the Moray Firth, and so on. A special radar system has even been set up to monitor bird movements through the wind-generator blades.

The public tends to think of the sea as an area to be left wild and untouched. It is not risk-free for a company to set up major infrastructure that could harm nature, as this could also damage their public image. To convince industry of the benefits of exploiting the potential of offshore wind energy, DOWNVinD therefore had to lay all its cards on the table.

According to Allan MacAskill, "The greatest challenge for DOWNVinD is to create the technical conditions for developing large-scale, commercially viable projects. In other words, to set up wind farms with 200 wind generators, not just two like the Beatrice Wind Farm."

Matthieu Lethé

(1) *Delivering Offshore Wind Power in Europe*, www.ewea.org.

DOWNVInD
17 partners – 6 countries (UK-DE-DK-FR-NL-SE)
www.downvind.com
Wineur
5 partners – 3 countries (FR-NL-UK)
www.urban-wind.org
EWEA
www.ewea.org

Very small wind generators

While offshore wind generators can be viewed as the extra-large version, there is also an extra-small version: urban wind generators. Specially designed for built-up areas where winds behave highly randomly, these small wind generators are usually positioned on or near building roofs. Their design, tailored to suit these special conditions, differs significantly from that of conventional wind generators. The main difference is that the axis of rotation of urban wind generators is vertical rather than horizontal.

They have a fairly small capacity of between 1 kW and 20 kW (that is, between 0.001 MW and 0.02 MW), which does not allow them to supply all the requirements of an ordinary building. "This is probably their main drawback", admits Patrick Clément, coordinator of WINDEUR – a project to raise awareness and provide information on small wind turbines in an urban environment, which is 50 % funded by the European Commission (to the tune of €450 000). "As the output is quite low, manufacturers are not interested in them, and so costs remain high. Wind generators are in the same situation today as photovoltaic systems were 15 or so years ago: they were expensive because production was only on a small scale."

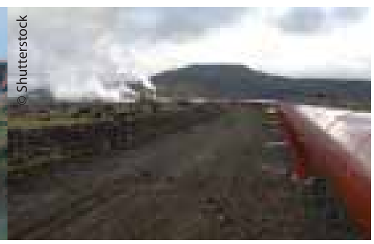
However, the technology is already highly developed and, while a few elements could still be improved, such as the profiles and the electronic starting and shut-down systems, several groups have launched projects of varying sizes. "The Netherlands and the UK are particularly proactive in this area", says Patrick Clément. "For instance, The Hague is developing a project for 50 or so small wind generators in the city. And France's electricity generation and distribution giant, Electricité de France (EDF), has applied to the European Commission for technological research funding. This is a sign of its potential."

Water and fire

Although wind energy is subject to the vagaries of the wind and solar energy to those of the Sun, the Earth has always offered two blue-chip energy sources: the water that flows continuously on its surface and the 'fire' in its belly. Although the exploitation of water for hydroelectric power is starting to reach its limit, fire still offers huge potential.

The Itaipu Dam – the world's most powerful dam – supplies nearly one quarter of Brazil's electric power. Such massive solutions cannot be envisaged in Europe, where the trend is to create mini-hydropower plants.

© CNRS Photothèque Hervé Thery



Hot water being piped through a volcanic area in Iceland.

© Shutterstock

Humans have been exploiting the power of water for thousands of years, in the form of tides or water courses. The use of dams to convert water into electricity, which began in the 19th century, offers a renewable and controlled form of energy. What is more, with hydroelectricity it is possible to gear electricity production to demand. For instance, the Grand'Maison Dam in the French Alps can deliver a whopping 1 800 MW of power in only two minutes. According to the International Energy Agency (IEA), dams supply approximately 16% of the world's electricity production, placing hydroelectric power in top position among the renewables.

However hydroelectric plants require a specific type of terrain and large expanses of land, which is problematic in environmental, economic and social terms, not to say alarming in the case of China's planned Three Gorges Dam. In addition to the indirect impact on the ecosystem of slowing down water courses, the performance of dams in terms of the greenhouse-gas effect is undermined by the large amounts of methane generated by plant decomposition in the flooded areas.

It is highly unlikely that Europe will embark on large-scale hydro projects in the future, as research will focus instead on mini-hydropower plants. These are turbines that generate less than 1 MW, situated along rivers and their tributaries, which require only a two-metre difference in height. Well suited to decentralised energy production, mini-hydropower plants will have only a limited impact on Europe's electricity production because they have a maximum potential of only around 1.5 GW.

Prospects for geothermal energy

The reverse is true of geothermal energy, as there is plenty of potential for exploiting it. Not only on the Earth's surface, where heat pumps can be used to recover a portion of the solar radiation absorbed by the ground, but more important, at depth. In fact, under our very feet there is a real boiler fuelled by the natural disintegration of the radioactive elements in rocks (uranium, thorium, potassium) and, to a lesser extent, by the primitive heat accumulated during the Earth's accretion phase.

More often than not, surface geothermal energy is used as additional heating for domestic circuits or heating and hot-water units. The heat is simply recovered by a fluid contained in a heat exchange system buried a few metres deep.

To channel enough power to produce electricity, we need to turn to deep geothermal energy. The further we go beneath the Earth's crust, the higher the temperature. In fact it increases by an average of 3 °C every hectometre, with wide local variations. The techniques used depend on both the depth of the bore hole, which can descend as much as five kilometres below the surface, and the type of geology. Sometimes hot springs can be used, otherwise cold water is injected into cracks in rocks. Once heated, pressure causes the water to rise and it is used to drive turbines (1).

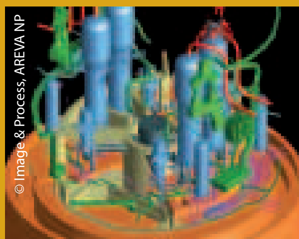
M.L.

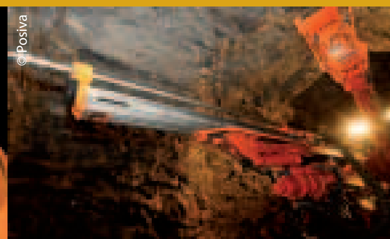
(1) Geothermal energy will be the subject of an upcoming research*eu special issue on earth science.

Three Gorges Dam

Under construction since 1994, this grandiose piece of civil engineering spanning the Yangtze River, with its power station exceeding 22 000 MW in capacity, is expected to supply China with nearly 90 Terawatt/h of electricity as from 2009. However, the project has exacted a price: at least 1.2 million displaced people and 600 km² of farming land and forest flooded by the artificial lake (the surface area of the retaining reservoir spanning more than 600 km of river could total 58 000 km²). According to the Ecological Society of America, Chinese biologists estimate that the reservoir area presently harbours 6 400 plant species, 3 500 insect species, 350 fish species and 500 species of terrestrial vertebrate, one-fifth of which are mammals.

A large number of the threatened species are endemic, such as the Chinese sturgeon and the Yangtze dolphin.





The "big" energies

What should we do with nuclear energy? The debate centres on two contrasting views of the threat posed. Some view the risk in terms of our ability to control it. Others view it in terms of the price we will pay if we fail to control it.

Research is focusing on the means for eliminating all the hazards: fission in upcoming fourth generation systems, hypothetical fusion in the distant future and waste management. This is because no prospective scenario manages to remove nuclear from the energy equation. We simply need electricity too much.

Now electricity is materialising before our eyes: it is being converted into hydrogen, which can be stored and transported, then reconverted into electricity in a fuel cell, with water as its only waste product. This huge potential means that electric cars are just around the corner. And the big advantage is that hydrogen, which is being hailed as tomorrow's number-one energy carrier, can be produced simply using the Sun and water.

Generation four: fis

The nuclear energy sector – which produces 35% of the European Union's electricity – offers real potential for reducing hydrocarbon use. Although nuclear energy is neutral in terms of its greenhouse effect and is capable of generating a large amount of power, it also burns a limited resource, produces bulky waste and poses an enormous risk. How can these failings be mitigated and the nuclear industry's economic competitiveness increased? This is the challenge which the fourth generation of reactors intends to take up.

3D virtual image of the third-generation EPR reactor
The first one is under construction in Finland.

Nuclear energy has come back into favour after two difficult decades: in late 2007, the *AREVA* industrial group met with the French and Chinese presidents to sign a contract to supply China with two *European pressurised water reactors* (EPR). Another order from the world nuclear energy leader has led to the construction of the first pressurised reactor in Finland, which is expected to come into service in 2011 after a two-year delay and a further injection of funding.

EPR is the third generation of nuclear reactors. Although it has been improved, it burns uranium 235 and is incapable of mass-recycling the uranium from its spent fuel, meaning that it does not resolve the problem of limited fuel resources. "We know for certain that if nuclear energy continues to be developed using the current pressurised water reactors, which burn uranium 235 (representing less than 1% of the total content of natural uranium), three-quarters of known resources will have been committed by around the middle of the 21st century," says Frank Carré, Deputy Director of the French Atomic Energy Commission's Nuclear Development and Innovation Division.

Burning all the uranium

The current technology uses water both as a moderator to reduce the velocity of nuclear reactions in the core of the reactor and as a heat-transfer fluid, transferring heat to the exchangers that generate the steam to drive a turbogenerator. This technology does not allow the 99% of uranium 238 in natural uranium to be burned for fuel. In the case of pressurised water reactors, which predominate at present, the uranium needs to be enriched with 3–5% of uranium 235 to make it suitable for burning.

However, the sustainable development challenge demands more: it calls for a fourth generation of fast-neutron nuclear reactors capable of burning all the uranium by converting it into plutonium. A number of initiatives testify to renewed interest in this technology, which has led to the creation of several prototypes since the 1960s. Apart from national projects in India, China and Russia, there is the *Generation IV* International Forum of leading nuclear technology nations, the International Atomic Energy Agency (IAEA) International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO), the United States *Global Nuclear Energy Partnership* (*GNEP*), and the European Union *Sustainable Nuclear Energy Platform*.

France, the United States and Japan are planning to build prototypes of sodium-cooled reactors in around 2025. Sodium is another heat-transfer medium that has been subject to intensive research. Sodium does not moderate the neutrons, allowing their velocity to convert natural uranium into plutonium (itself a nuclear fuel) and even to regenerate it efficiently, allowing the plutonium to be recycled roughly 10 times. This saves on uranium and reduces the amount of waste. A further advantage is that the large stocks of depleted uranium from existing nuclear power stations (220 000 tonnes in France) can be used as a fuel reserve.

Cooperation not competition

However, for the time being the excessive cost of this hypothetical technology limits its commercial viability, unless pressure on the uranium market makes it competitive soon. "Russia, India, Japan and China continued to develop these reactors after the United States stopped in the late 1970s and Europe stopped in 1998 when it closed down its Superphenix fast breeder reactor in France. In 2010, India is set to launch a prototype to generate 500 MW of electricity" (1). China is also in the world fast-neutron race with an experimental reactor planned for 2010.

At the moment, the technological challenges are so great that the rivals of tomorrow are joining forces. This has led to the *Generation IV* international forum, which includes the United

sion reinvented

States, France, Japan, South Korea, South Africa, Brazil, Argentina, the United Kingdom, Canada, Switzerland, the European nuclear power nations (EURATOM) as well as, most recently, China and Russia. Between 2000 and 2002, experts worked to select six potentially important systems for the 21st century. Grouped under the title "Generation IV nuclear energy systems", they have not all reached the same degree of maturity.

Six potential technologies

Apart from sodium-cooled fast reactors, there is also renewed interested in very-high-temperature reactors. "The international effort in very-high-temperature technology has been revived by projects for the Pebble Bed Modular Reactor (PBMR) in South Africa (planned for 2014) and the Next Generation Nuclear Plant (NGNP) in the United States (planned for around 2020)." This technology could extend nuclear power applications to include industrial-heat generation, in particular for the production of hydrogen, synthetic fuels and seawater desalination to produce drinking water, all of which are key resources for the future.

Two other innovative technologies involve developing new heat-transfer mediums for fast-neutron, lead and helium gas systems. "As gas is not such a good heat-transfer medium as sodium, gas-cooled fast reactors call for the development of refractory fuels that are able to withstand cooling accidents. On the other hand, compared to liquid-metal-cooled reactors (sodium and lead), they offer the advantage of a monophasic, chemically inert heat-transfer medium and easier access for in-service inspection and repairs."

The last two technologies, molten-salt reactors and supercritical-water-cooled reactors, are seen as longer-term solutions for which the prototype-building phase is still a long way off.

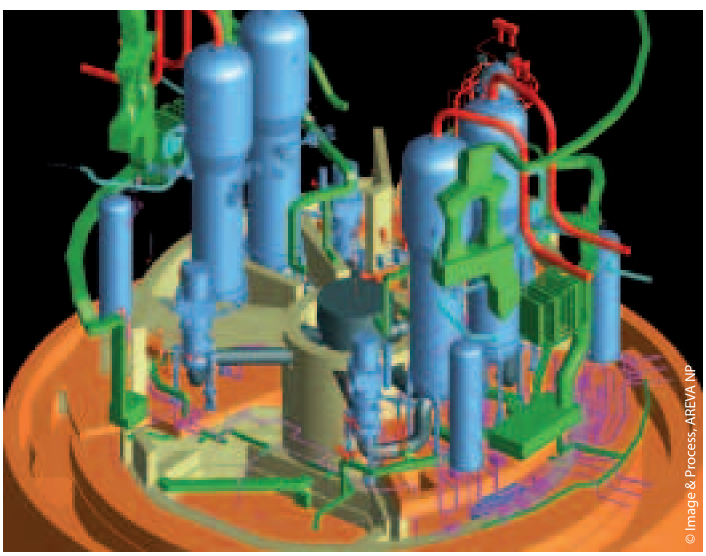
The risks

All these systems will need to satisfy safety requirements, which have been stepped up markedly since the Chernobyl accident in 1986 and the attack on the *World Trade Center* in 2001. The systems will rely on robust containment envelopes and an accident-management system that minimises the need for human intervention – in particular for evacuating the reactor's shut-down power. The risk of proliferation would be managed by a combination of IAEA controls, recycling methods deterring the diversion of nuclear material and regional fuel cycle centres offering their services to countries operating reactors (supplying fuel and taking back spent fuel). Although this would spare such countries from equipping themselves with potentially hazardous technologies, it would also create an imbalance with nations that control the entire technology chain, in itself posing a geopolitical risk.

The advent of generation IV nuclear energy systems, which are set to play a key role in the world energy balance, appears to be heavily dependent on technology development prospects, environmental concerns and economic strategies. Their future exploration will also need to take into account rival non-nuclear energies and society's acceptance of such energies.

Axel Meunier

(1) All quotes are from Frank Carré.



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Virtual image of the primary circuit in the EPR reactor. It comprises mainly the reactor vessel, steam generators, pressuriser and reactor coolant pumps.

What about fusion?

Just like today's reactors, fourth generation systems are still based on the fission principle, where a very heavy nucleus (uranium or plutonium) is struck by a neutron to split it into two lighter nuclei. The result is energy and the neutrons that allow the reaction to continue.

Conversely, nuclear fusion, for which the ITER facility currently under construction at Cadarache in France represents an important demonstration phase, relies on the fusion of two light nuclei (deuterium and tritium in a first phase) into a heavier nucleus (helium). The result is energy and a neutron that plays an essential role in regenerating tritium. However, the fusion reaction can only occur in plasma at a temperature of some 100 million degrees, and ITER must demonstrate that it can be controlled in the presence of nuclear reactions. The expected next phase, in around 2040, is the construction of a demonstration reactor (DEMO) that will generate electricity and regenerate the tritium consumed. By that date, fourth-generation fission systems are expected to already be in commercial operation.

Finland buries its waste

Does the disposal of radioactive materials in geological formations really enable them to be stored safely for several hundred thousand years? Two countries have taken the plunge: the United States, with its Yucca Mountain Repository, and Finland, which is generally considered to be the world's geological-storage pioneer.

The work currently under way to excavate Finland's Onkalo underground storage facility will have reached a depth of 300 metres in 2008, that is to say, three-quarters of the planned depth for the disposal of radioactive waste. The final studies on the safety of geological containment will then be conducted *in situ* before the facility is allowed to enter into operation.

Radioactive waste is extremely bulky. Although, according to French *Atomic Energy Commission* figures, it represents less than one kilogram per inhabitant per year in France (the country with the highest nuclear-electricity share in the world), the planet as a whole produces a massive 12 000 tons of high-level radioactive waste every year, mainly in the form of spent nuclear fuel from the reactor core. Finland's definitive solution is to bury spent fuel 500 metres below ground level, in the deep geological formation of crystalline rocks in the Baltic Shield, which is reputedly free of seismic activity. The site is in western Finland, close to the Olkiluoto nuclear power station. Work started in 2004 with the construction of a rock characterisation laboratory to verify the underground rock's properties and behaviour.

"The nuclear fuel rods will be placed inside six-metre-tall copper containers measuring one metre in diameter, coated in a 35-centimetre layer of bentonite, a natural type of clay. After the storage facility comes into service in 2020, it will be filled gradually over a period of 100–120 years", explains Tero Varjoranta, Director of the Nuclear Waste and Material Regulation Department of the Finnish Radiation and Nuclear Safety Authority (STUK). The facility will be the final resting place for spent fuel from Finland's two existing power stations, Olkiluoto and Loviisa, as well as from the future European pressurised water reactor planned for 2011.

In 2001, virtually the entire Finnish parliament endorsed the decision in principle to construct the site, bringing to an end a debate that had begun in 1983. "The 1994 Nuclear Energy Act stipulates that all nuclear waste produced in Finland shall be stored in the country. The company *Posiva*, project manager of the works, was created in 1995 jointly by *TVO* and *Fortum*, the firms that manage Finland's two Finnish nuclear power stations. It is therefore the industries producing the waste that finance long-term waste management, according to the *polluter-pays* principle." (1)

The basic principle for the permanent disposal of irradiated nuclear fuel is to isolate it for an unbelievably long time: "When spent fuel leaves the power station, it is four million times more radioactive than natural uranium. It only returns to the background level of radioactivity after 250 000 years." Safety will be maintained entirely passively, without human intervention. "The copper, bentonite and uranium used for storage are naturally occurring materials; we know how they have behaved for millions of years. It would be problematic for us to integrate artificial titanium structures, as it is still too soon to assess their safety."

Advocates of this technology see it as a sort of return to nature. Since it is not possible to predict the evolution of human society so far ahead, the odds are that the very existence of the site will be forgotten. In any case, the knowledge of its whereabouts will be preserved for the first 350 years, during which time the radioactivity level will be monitored from the Earth's surface. Does this comply with the ethic of sustainability, which requires that the planet should be left clean for future generations?

In any case, the Finnish initiative has created a precedent and is ahead of other more futuristic solutions such as transmuting long-lived waste into short-lived elements. This new alchemy will perhaps come to supplement another type of transformation: converting today's waste into the fuel of tomorrow for the fourth-generation reactors that are expected to spring up in the 21st century.

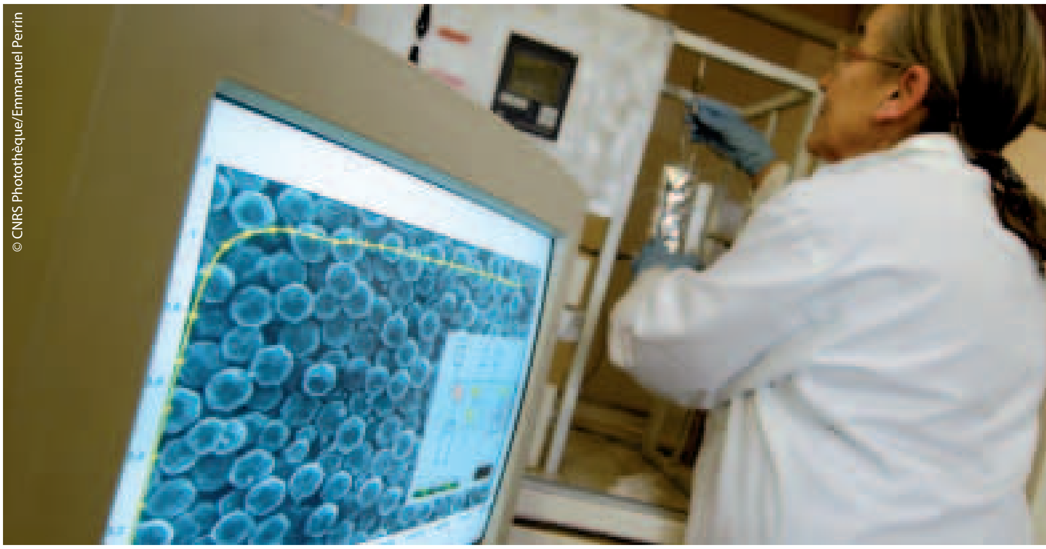
A.M.

(1) All quotes are from Tero Varjoranta.

When will the hydrogen age arrive?

Everywhere and yet nowhere, hydrogen abounds in the Universe and in the media, where it promises to power the fuel cells of tomorrow's cars. Hydrogen is highly reactive and virtually impossible to find on Earth in a molecular state. However, since it can be isolated, stored and transported, hydrogen is set to become the number-one clean energy carrier of the future.

Development of new catalysts for fuel cells.



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With one electron and one proton, hydrogen is the simplest and most abundant chemical element in the Universe, of which it is estimated to represent more than 75% of the elemental mass. The Sun and most of the stars are composed mainly of hydrogen. What is more, the energy emitted by these stars comes from the thermonuclear fusion of hydrogen. Traces of hydrogen, a colourless, odourless, tasteless diatomic gas with the molecular formula H_2, can be found in the atmosphere. As it is highly reactive, it bonds easily with other elements to form compounds such as water, sugar, proteins and even hydrocarbons.

At present, H_2 is used mainly by the petrochemical industry to produce ammonia. However, in the future it is planned to use hydrogen as an energy carrier like electricity, with the enormous advantage that it is easier to store than electricity.

Cells come up trumps

In a bid to escape the era of fossil energies, especially in the transport sector, all eyes are turned to the electric car. However, conventional storage batteries have serious drawbacks. Apart from being rather bulky and having very limited autonomy, they tend to age prematurely and their components are polluting both to manufacture and recycle. In this impasse, hydrogen is opening up a new opportunity – the hydrogen fuel cell. The fuel cell combines oxygen in the ambient air with the hydrogen contained in a storage tank to produce electricity and heat, without emitting either greenhouse gases or noise, and the only waste product is… a small amount of water. This 'miracle' is produced in the electrochemical cell, where two electrodes are brought into contact with an ion-conducting medium, the electrolyte.

The oxygen on the cathode attracts the hydrogen atoms on the anode. However, to reach the oxygen, the hydrogen atoms are forced to divide because the electrolyte blocks the electrons. The electrons then travel through an external circuit, generating a current, whereas the $H+$ ions cross the electrolyte •••

to join the oxygen. As this is a highly exothermic reaction and yields an energy efficiency of up to 60% (compared with 20–30% for conventional combustion engines), it can be envisaged for a range of highly attractive applications, especially cars.

The fuel cell concept was discovered by William R. Grove in 1839 but lay in a drawer gathering dust until the 1960s, when NASA retrieved it for the *Gemini* and *Apollo* space programmes. After that, the prospects for the fuel cell grew, and several cell variants emerged, either using different types of electrolyte, different operating temperatures or 'fuels' other than hydrogen [1]. In the 1990s, the car industry released its first high-performance prototypes. Their proton exchange membrane fuel cells (PEMFC) use a platinum catalyst to reduce the reaction temperature to between 80 °C and 100 °C. At present, researchers are also investigating less expensive catalyst materials.

However, numerous obstacles stand in the way of creating a real hydrogen fuel chain in the transport sector: unlike oil, the 'fuel' in fuel cells does not actually exist on the planet, and the reactivity of this volatile gas raises safety issues for storage, transportation and distribution.

Snags with hydrogen production

At present, hydrogen is produced by its main consumers – that is to say, oil refineries and fertiliser factories. It is produced using one of three techniques for decomposing hydrocarbon: steam reforming, partial oxidation and autothermal reforming. Steam reforming involves dissociating carbonaceous molecules in the presence of steam and heat. Although steam reforming offers high energy efficiency of 40%, it is an endothermic technique. Partial oxidation is a reaction from the combustion of hydrocarbons. Although it has the advantage of being exothermic, partial oxidation produces less hydrogen. Autothermal reforming is a combination of the latter two techniques: the heat released by partial oxidation is fed back into the steam-reforming process to enhance energy efficiency.

However, not only do these techniques rely on a dwindling supply of hydrocarbons, they also produce greenhouse gases. In order to set ourselves on the path to clean and sustainable transport systems, it is therefore crucial to use alternative hydrogen-production techniques.

Hydro-alternative

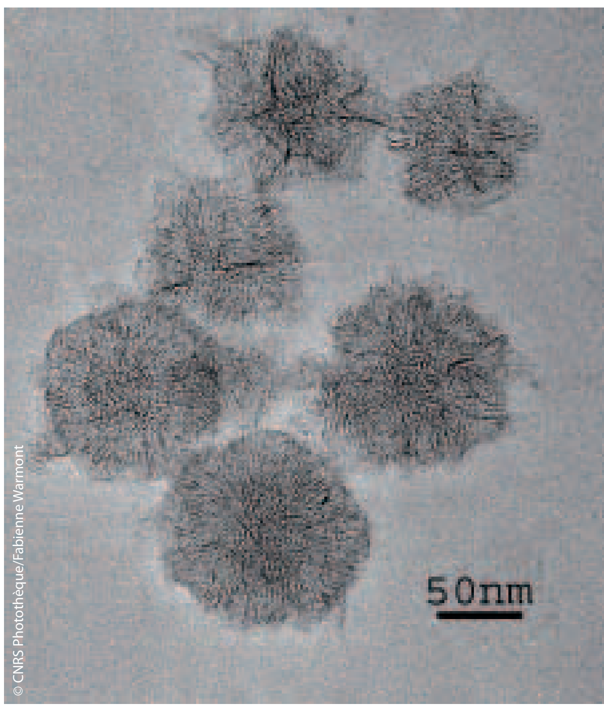
One such alternative is hydrolysis – the electrolysis of water. When the H_2O molecule is subjected to a direct electric current, its H and O components are isolated. The base elements – water and electricity – are available just about everywhere, at least in industrialised countries. However, it requires a lot of electricity to divide one of the world's most stable molecules at ambient temperature. If the electricity has to come from conventional power stations, the environmental advantage is lost. And, economically speaking, division is not yet cost-effective enough compared with hydrocarbon-based reactions.

This makes *high-temperature electrolysis* (HTE) a more interesting alternative. At high temperature, the heat provides part of the energy required for the reaction, increasing energy efficiency. HTE consumes less electricity and presents real economic advantages, provided that the heat comes from a natural resource like the Sun.

The challenge of HydroSOL

Would it be possible to produce hydrogen without using electricity at all? This is the challenge that European research has been endeavouring to meet since 2002 with the *HydroSOL* project, which is 50% financed by the European Commission. The project is coordinated by the Laboratory of Aerosol and Particle Technology of the *Chemical Process Engineering Research Institute at the Centre for Research and Technology-Hellas* (*CPERI/CERTH*) in Greece. Project researchers are developing an innovative thermochemical reactor that produces hydrogen using solar energy alone. HydroSOL was awarded the European Union Descartes Prize for Research in 2007, as well as the *International Partnership for Hydrogen Economy* (*IPHE*) inaugural 2006 Technical Achievement Award.

Carbon nanohorns, forming structures 80–100 nm in diameter, which could offer a solution for the safe and efficient storage of hydrogen.



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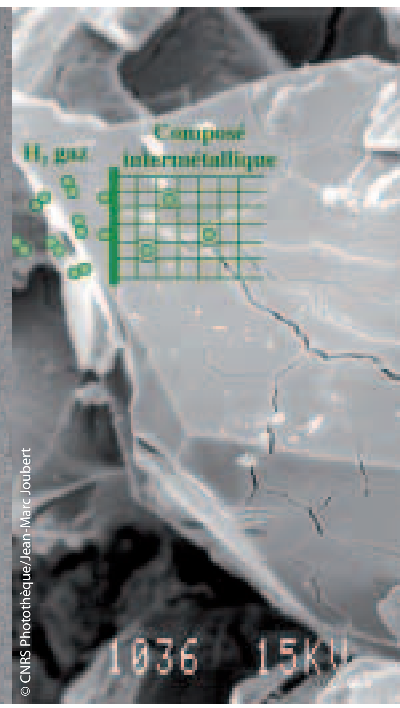
Grain of hydride (hydrogen sponge) seen under a scanning microscope, showing the fracturing of the intermetallic compound after



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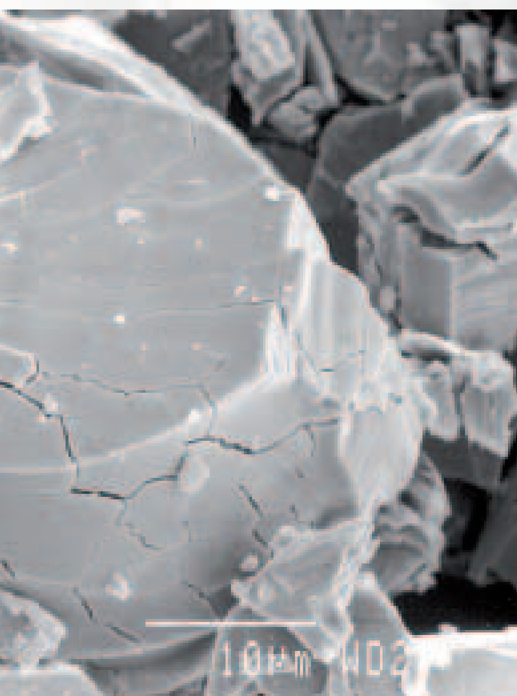
"The theoretical concept is very simple", explains Athanasios Konstandopoulos, HydroSOL coordinator and director of *CERTH*. "Concentrated solar radiation is used to heat water and the resulting steam traverses the reactor, where the hydrogen and oxygen are separated at high temperature by oxidation-reduction. The economic gains are enormous: the reagents are inexpensive and the sunny regions suited to hosting the solar tower power plants for this clean hydrogen-production method tend to be economically depressed areas."

The reactor is a refractory-ceramic monolith capable of absorbing solar radiation and reaching a temperature of 1 100 °C. The steam travels through the reactor's honeycomb structure with its many tiny parallel channels. Each channel is coated with active nanoparticles which absorb and trap oxygen, leaving the hydrogen to continue on it way. In a second phase, solar heat releases the oxygen from the nanomaterial to regenerate it, allowing a new cycle to commence.

inserting hydrogen. Research is being conducted into using this material for the hydrogen tank in fuel cells.



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Fuel cells in cities

In 2006, the first major experiment using hydrogen transport vehicles ended in success. The *CUTE* (*Clean Urban Transport for Europe*) project, in which nine European cities participated, involved running 27 buses on fuel cells. More than half of the hydrogen contained in the cells was produced using renewable energy. More than 4 million passengers were transported without a single incident and, more importantly, without any polluting emissions.

The CUTE partners were surprised at the efficiency, life span and reliability of the cells and decided to extend the experiment with *HyFLEET:CUTE*. The new project involves 31 participants around the world, including Iceland, Australia and China, and has been endowed with a budget of €43 million (€19 million of which comes from the European Commission) for operating some 47 hydrogen-powered buses. "Cooperation with other continents brings great benefits", explains the project's coordinator, Monika Kentzler. "It enables us to test the designs under a wide variety of conditions, whilst at the same time showcasing European technology and know-how."

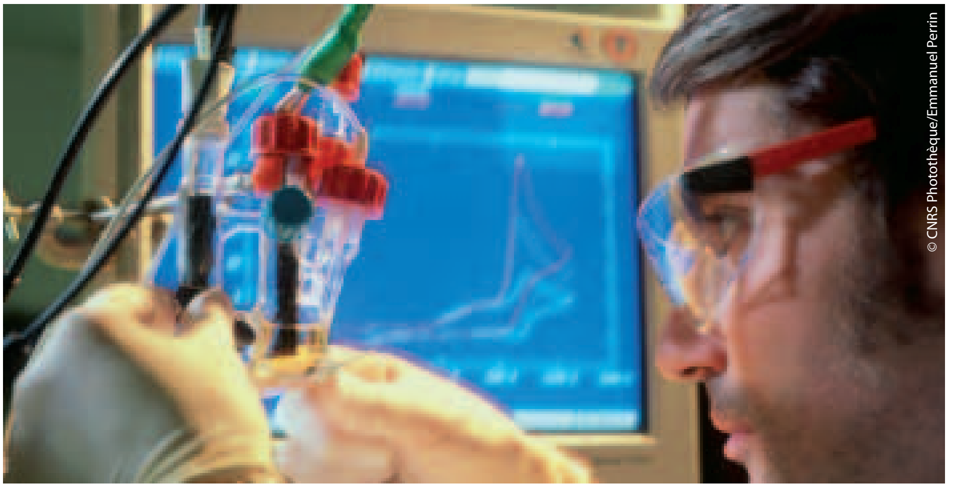
HyFLEET:CUTE aims to develop not only hydrogen-powered vehicles, but also hydrogen-production and refuelling techniques. The cities involved will each set up their own refuelling system. Other techniques are being tested too. For instance, Berlin is operating 14 internal-combustion-engine buses powered directly by hydrogen.

"The two technologies are close to being marketed", assures Monika Kentzler. "Although production capacities are still too small to meet the partners' requirements, we expect to be able to satisfy them by 2015–20. A significant research effort is also required in the area of infrastructure, to ensure quick, easy and reliable refuelling. In addition, we must develop renewable hydrogen-production methods, to reduce this new fuel's environmental and energy footprint to a minimum, whilst reducing the costs of the hydrogen fuel chain as a whole."

Solid oxide fuel cells ready for testing. Researchers have succeeded in reducing their operating temperature by 100 °C.

© CNRS Photothèque/François Jannin

"In order to test the reactor, we integrated it into a small pilot concentrated solar power station", explains Athanasios Konstandopoulos. It was used to produce hydrogen continuously in 40 cycles over the space of two days. This successful project is continuing with *HydroSOL-2*, launched in 2005, again with European Commission funding. A 100 kW power station was inaugurated on 31 March 2008 on the site of the Almeria Solar Platform in Spain. The project aims to cut production costs to arrive at a selling price of 6 euro cents/kWh. "After two years of research, we ought then to design, or even build, a 1 MW-capacity pilot power station, which is a scale that is of interest to investors. We want to mass-produce hydrogen at a competitive price in the next 5–10 years", says the coordinator.



Electrocatalytic hydrogen evolution by cobalt complexes.

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Storing H_2

Problems of storage and transportation are also holding back the introduction of hydrogen fuel. 14 times lighter than air, weight for weight, hydrogen contains more than twice the energy of natural gas and nearly three times that of oil. However, the memory of the fire that destroyed the *Hindenburg* zeppelin near New York in 1937 serves to remind us that this gas raises safety issues, being highly flammable in the presence of oxygen.

Hydrogen can be compressed (250–700 bars) in gas bottles or underground tanks – the most common form of storage. However, it requires energy to place gas under pressure and the storage tanks needed are still too large. Although liquefaction (at a temperature of -253°C at atmospheric pressure) provides a solution to the volume problem of storing hydrogen, cryogenic techniques are also energy-consuming and require highly insulating storage materials (a field where lighter composites are increasingly supplanting steel).

However, in the future, hydrogen could well be stored in a solid state: a hydride can be made by filling the fractures in light metal alloys with hydrogen ions. Since this absorption reaction is exothermic, the host material then needs to be heated to release the hydrogen. D.K. Ross, from the *University of Salford* (UK), is coordinating the European project *HyTRAIN* (2), a research training network that also provides a multidisciplinary forum to identify new candidate materials for hydrogen storage, as well as methods of synthesising them. "Solid-state hydrogen storage would avoid the risks of high-pressure storage, provided that the absorption/release reactions take place at an acceptable rate, which can be achieved at a moderate temperature", explains Ross.

A Swiss–Norwegian team participating in the *HyTRAIN* project recently discovered an unstable form of $LiBH_4$, which could be a useful candidate for solid storage. "However, these materials are still very difficult to handle", cautions D.K. Ross. "The *HyTRAIN* project is also paving the way for hybrid tank designs that combine the solid storage and pressurised gas methods. The potential for solid hydrogen will be enormous if hydrogen energy takes off. Nanostructured materials could be bulk stored for use in refuelling stations, for example."

When will the hydrogen economy arrive?

A total of €470 million from the budget of the European Union's Seventh Framework Programme for 2007–13 (FP7) has been earmarked for research into hydrogen and fuel cells. According to several estimates, this new clean-energy carrier will start to replace hydrocarbons in the transport sector and stationary applications as from 2020. By then, Europe expects to be using hydrogen to cover 5% of energy requirements for its transport sector. This would appear to be a fairly modest objective. Could implementation be speeded up? 17 governments and the European Commission have been working in the *IPHE* since 2003 to hasten the transition to the hydrogen economy by coordinating investments more effectively.

Hydrogen has the potential to meet our energy needs. However, the technology and infrastructure needed to use hydrogen on a mass scale will not be operational for several decades. And in an energy market that harbours powerful interests, it is not necessarily a top priority to develop hydrogen power. Meanwhile, combustion engines will keep on running…

Delphine d'Hoop

(1) A cell using methanol for fuel, the *direct methanol fuel cell* (*DMFC*), is likely to introduce fuel cells into everyday life, to power telephones, portable computers and multimedia devices. These cells avoid a number of problems associated with hydrogen fuel and are already performing five times better than their lithium-ion counterparts.
(2) *HYdrogen Storage Research TRAINing Network.*

HydroSOL
4 partners – 4 countries (GR, DE, DK, UK)
www.certh.gr

HydroSOL-2
5 partners – 5 countries (ES, GR, DE, DK, UK)
http://www.certh.gr

HyTRAIN
17 partners, 11 countries (BE, CH, DE, ES, FR, IT, LT, NW, PL, SE, UK)
www.salford.ac.uk

Other resources
h2euro.org/
hfpeurope.org
h2mobility.org
h2moves.eu

What when the oil runs out?

Could we live off the planet's yield alone, instead of raiding its capital as we are now doing with fossil energies? While the leading institutions are aiming to reassure, foreseeing a gradual process of change to which our societies will slowly adapt, other thinkers are sounding the alarm and predicting huge upheavals unless there is a radical break from the old ways.

There are some momentous questions to be answered. Can agriculture produce energy while also feeding the entire planet? Can we just leave things up to governments or should individuals get organised to deal with the new energy order? And what will be the role of research, which some accuse of subservience to political ideology? Three questions, limitless answers…

Star billing for science

As it is an innovation creator, science is bound to play a key role in the coming energy revolution. It has gradually taken on an advisory position in the political world, a trend reflected by the Intergovernmental Panel on Climate Change (IPCC), which has increasingly come to be considered – by the media at least – as the leading authority on the matter.

Those who are relying on research to rescue us from the oil age will have to wait a while longer because, in the short term, research could keep us there. "The oil age is far from over", warns Antonio Pflüger, Head of the Energy Technology Collaboration Division of the *International Energy Agency* (*IEA*). "There are still numerous potentially exploitable resources across the world. R&D investments aimed at developing new modes for extracting hydrocarbons and new methods for generating them will most likely increase reserves over the coming decades. Non-conventional oil deposits, such as offshore wells in the Arctic Ocean that cannot be exploited using current technology, or oil shales that still cost too much to convert into oil, will almost certainly provide reserves in the near future."

The IEA is also banking on improving energy efficiency. "This is a crucial strategy because it enables us to not only save resources but also reduce carbon dioxide emissions."

These measures should allow us to put off an evil day for which Antonio Pflüger warns us we must already start preparing, especially in the area of transport, which consumes some 60% of the world's oil. "There is no doubt that research on electric and hybrid cars and on new fuels such as hydrogen and biomass heralds the future."

Business as usual?

However, not everybody agrees with the IEA's recommended R&D investment strategy.

Some people are worried about concentrating too much research effort on as-yet unexploited fossil resources because this would only mean prolonging an already obsolete model that does not allow our societies to escape their dependency on oil.

According to Hermann Scheer, Chairman of the *World Council for Renewable Energy* (*WCRE*) and of the *Eurosolar* association, continuing to invest in fossil energies permanently undermines our prospects for a sustainable future. In his latest book, Hermann Scheer warns that if we fail to go over to renewable energies in the next two decades, we can expect our world to be rocked by violent conflicts over the control of resources. To shift from one mode of energy to another, not only must we continue to develop renewable energies, we must also end the need for fossil and nuclear energies. This means we have to embark on one type of energy while at the same time quitting another. We therefore have to stop wasting thousands of billions on building new thermal and nuclear power plants, which will only serve to entrench conventional energy-supply structures for decades to come. Renewable energies must be deployed both qualitatively and quantitatively much faster than current government programmes foresee – especially since most governments' overall plan and means of deployment will not even enable them to achieve the stated objectives"(1).

As for energy efficiency measures, David Strahan, consultant for the *Oil Depletion Analysis Centre* (*ODAC*) and journalist specialising in peak oil issues, doubts that they will lead to real savings in oil. "We have been investing in energy efficiency since the first oil crisis in 1974. However, these improvements have served only to cut the cost of energy, which in the end has led to increased consumption. It is no use improving efficiency if we do not adopt a parallel strategy of rationalising energy use."

Carrie Pottinger, IEA Energy Technology Coordinator, accepts this argument, adding that there is no single solution for supplying energy. "The key issue is not what will be the predominant energy source. The real issue at stake is whether governments are prepared to implement appropriate policies to allow replacement solutions to become cost-effective and be deployed on a large scale. Such solutions should play a key role in our energy markets right now if we are to avoid supply problems in the future. Judging by current oil price rises and the way certain geopolitical issues are evolving, it is a future that might be closer than any of us suppose."

Independence at stake

How, then, should we direct the research that will shape tomorrow's innovations? Vital issues are at stake, because peak oil could well trigger an economic crisis of unprecedented proportions. Such a crisis, compounded by the expected impact of global warming, could well form an explosive social cocktail. Can science therefore support the politicians' R&D investment strategy by developing

future scenarios that would help us to take the right decisions?

In any event, the rise of the IPCC in recent years seems to have led the scientific world to gradually adopt a political advisory role. It is something that IPCC Chairman, Rajendra Pachauri, welcomes. “The fact that the world’s leaders and opinion-makers have been so profoundly influenced by the IPCC conclusions is, in my view, a tremendous advance, which could be adopted in all political spheres. We are now entering a knowledge age. If we really wish to develop the world sustainably, then knowledge must guide efforts to this end.”

As for the independence of science – so dear to researchers precisely because it guarantees their credibility – the IPCC Chairman is reassuring. “Knowledge cannot be controlled or geared to the wishes of the public authorities. We must do our utmost to prevent politics from interfering with scientific results. Our duty is precisely to disseminate all scientifically established knowledge to the public. It is a duty that I heartily endorse.”

Although the IPCC brings together the views of many researchers whom it is hard to imagine all subscribing to a common ideology, the fact remains that their conclusions (which have been ‘re-examined’ by decision-makers) are based on a compromise, which is normally more the reserve of cabinets than of laboratories. And since the media quickly turns a compromise into consensus, then into fact, it is more difficult for some people’s reservations to receive media coverage, particularly those who contest the human-induced origin of global warming. Of course these *global warming sceptics* – who have even been described as *revisionists* – often discredit their own case with their aggressive rhetoric denouncing a widespread environmentalist plot, or their involvement with politicians – a White House special adviser here, a scientist-cum-minister there. But if a serious scientist were investigating an alternative origin for global warming (such as the action of the Sun), could they receive funding for their research in the current context? Let’s hope that humans are indeed the culprits, if all investigations are being focused entirely in this direction.

The IPCC could herald a fundamental change in the role of science in the coming century, especially in its relations with politicians and with civil society, mainly through the media where its voice is increasingly important but rarely challenged. More than ever, this calls for caution and critical thinking.

Jean-Pierre Geets, Julie Van Rossom

(1) Hermann SCHEER, *Energy autonomy: the economic, social and technological case for renewable energy*, Earthscan/James & James, 2007.

In a world without hydrocarbons, it is possible to imagine no longer taking a plane, abandoning the car, forgetting about synthetic clothing and using wood for heating. But could we stop eating?

End of oil

"In the West, approximately 10 calories of hydrocarbons are required to produce one calorie of food. In short, we convert oil into food via the Earth. It is as though we were eating oil", says David Strahan (1) wryly.

The green revolution that began in the 1940s has significantly increased the world's agricultural yield through the introduction of new intensive production techniques. These have triggered unprecedented demographic growth, doubling the world's population over the past five decades. It is a situation that bodes ill for world food security in the years following peak oil. Indeed, without oil, not only would it be impossible to run farming machinery or to transport products or raw materials, worse still, it would also be impossible to synthesise agricultural inputs from the petrochemical industry (fertilisers, herbicides and pesticides).

"Under these circumstances, the European Union's biofuel policy is totally idiotic and counter-productive", exclaims Strahan. Although an oil shortage would jeopardise the world's access to the vital resource of food, our politicians are planning to deprive the food industry of a portion of agricultural production in favour of transport. What is more, this would achieve rather mixed results: "Based on IEA statistics published in 2004, 20% of Europe's cultivable area would need to be given over to biofuel crops to produce barely 5% of our fuel needs. Even if we were to devote all our agricultural land to biofuel production, this would allow us to satisfy only 25% of our transport needs and we would starve in the process."

Back to basics

Giving over a portion of Europe's farmland to biofuels could compound an already critical problem: how to feed ourselves without the aid of petrochemicals. Using tried and tested ancestral farming methods, without inputs and without agricultural machinery, in short, without a single drop of oil? "In fact, the only means for ensuring world food security without oil may well be organic farming", says David Strahan. "However, such a transition raises a fundamental question: can the current yield be maintained?" Some people believe that, although organic farming would produce a low yield in the initial years, in the long term it could achieve the same yield as intensive farming. "That being so, it does make me wonder why our farmers spend so much money on pesticides, fertilisers and energy for driving machinery."

In spite of his doubts, David Strahan is optimistic. "Solutions already exist, especially for producing locally the energy needed to run basic agricultural machinery. For example, we could use biogas (methane) generated by fermenting farm waste, or else batteries charged by wind or solar energy. However, even if organic farming were to provide an equivalent yield, transporting farm produce to the consumer's plate remains a crucial problem. This means that the farming of the future will more than likely be locally-based."

Homo energetis

Vandana Shiva, symbolic figurehead of the alterglobalisation movement and Director of *Navdanya* and *India's Research Foundation for Science, Technology and Ecology*, goes a step further. She advocates quite simply returning to ancestral farming techniques. She places physical labour (animal but especially human) at the top of the green energy list. "State subsidies really must promote a return to traditional agriculture to put a stop not only to dependence on long-distance food supply

Tomorrow is another day

We know that our leaders are struggling to set in place effective preparatory measures today to pave the way for the energy transition of tomorrow. But what if they don't succeed?

chains, which are far too costly energy-wise, but also to the disastrous consequences of industrial farming on the climate. Industrial farming and the accompanying food trade are responsible for 25% of the world's carbon dioxide emissions", explains Shiva. "The true energy of the future is human energy."

That is, provided that human energy is available. "People would probably start moving back into rural areas because of the renewed need for labour", believes David Strahan. "However, this will not signal the end of cities. They are too highly populated. Transferring the entire urban population to the countryside would destroy the country wholesale. City-dwellers will most probably start growing food in their gardens or on rooftops to offset soaring world food costs. In my view, this will be a spontaneous movement: city-dwellers will take matters into their own hands to counter the food crisis unleashed by peak oil. One thing is certain, urban food will need to be produced in or around the city simply to save energy."

J.P.G., J.V.R.

(1) David Strahan, investigative journalist and author of "The Last Oil Shock: A Survival Guide to the Imminent Extinction of Petroleum Man".

"We have reached a human-induced impasse", explains David Wasdell, international coordinator of the *Meridian programme* and IPCC report-reviser specialising in the dynamics of climate change. "On the one hand, the age of unlimited energy is coming to an end. Demand is increasing while energy sources are becoming depleted and oil-extraction methods are increasingly costly. On the other hand, we are emitting too much CO_2, precisely because we favour hydrocarbons as our main energy source. It is high time to acknowledge the true nature of hydrocarbons. They are toxic and have no future, so we should no longer consider them as a limited resource to be shared, but as a real threat to humanity."

Heading for disaster

So what if the price of energy increases? Is that so worrying? "Perhaps one day we will look back nostalgically to the time we paid US$100 a barrel, because the price is very likely to rise to US$200", predicts David Strahan. He believes that soaring petrol prices could trigger a drastic rise in all prices, followed by job losses, a collapse in buying power and stagnant production. This would plunge the economy into an extremely dark age.

But surely 'the market' is there to regulate prices, say some? "Ultimately demand can only decrease because nobody will be able to afford to buy oil, which will cause prices to fall. But it will probably be too late by then because massive job losses are likely to be of much more concern to civil society than petrol prices. We must stop fixating on the oil price and concentrate instead on the consequences of its total depletion", warns Strahan. In his view, a scarcity of oil is likely to cause a total collapse of our economy, so much has this resource seeped into every aspect of human activity, including trade, industrial production and even the travel of individuals to and from their places of work. "Oil is rooted so deeply in our societies that an oil shortage will trigger a serious recession."

Structural myopia

Will our leaders be able to anticipate this threat and prepare the ground for a smooth transition to a hydrocarbon-free society? The IEA is pragmatic. "There are

●●● three prerequisites for catalysing innovation nationally", says Carrie Pottinger (1). "The first is a robust academic environment. The second is increased transfer of R&D results from academia to the private sector. Financing specifically targeted research will speed up the technological breakthroughs needed for innovations to emerge. The third prerequisite is a clear and consistent long-term government policy." The length of time required for catalysing innovation extends considerably beyond the *pro tempore* mandate of our political leaders. "Which poses a real challenge, given the nature of our democracies as well as changing priorities and people", adds Carrie Pottinger.

Perhaps, by their very nature, our democracies take too short-term a view to grasp such long-term issues. Some people believe that the very basis of the democratic system hinders the introduction of coherent measures. "Politicians are incapable of really adopting an effective long-term view. This stems chiefly from the nature of the electoral system itself", believes Simon Cooper, founder member of *The Converging World*, a British association that funds green energy projects in developing countries. "No politician would jeopardise their re-election prospects by imposing unpopular measures. As long-term action is hardly enticing, the public authorities systematically focus on short-term issues."

This is something that even some politicians acknowledge. "Problems such as peak oil and global warming, which require a planned response over the very long term, frighten leaders so much that they do not know how to react", says Jonathan Porritt, Chairman of the United Kingdom's *Sustainable Development Commission*. "Politicians will only take action if there is a crisis, if the supply of oil suddenly shrinks and triggers a spectacular price rise."

According to some, such an economic implosion could awaken collective awareness and trigger a radical change to a more sustainable lifestyle. "I think that this is a bit of a simplistic argument", replies Strahan, "because, apart from oil, there is still gas and coal, the consumption of which will increase and, with it, greenhouse gas emissions, which will compound the problem. And if peak oil were to precipitate the anticipated economic crash, then capital and wealth would shrink before our very eyes. Where, then, would we find the necessary investment to build all the new energy infrastructure that we would need?"

Resourcefulness?

Such a state of affairs could undermine democracy itself. "From the macroeconomic standpoint, I do not think that peak oil is beneficial for the democratic system. In fact the democratic system is a poor framework for the changes needed to counter the effects of this crisis, which explains the failure of all policies on the matter. A whole array of scenarios can therefore be envisaged, from greater local-community activism to the emergence of a form of authoritarianism within central government. One could even imagine a combination of the two".

Will the solution come from civil society, then? According to Simon Cooper, "political action is not enough; only individual initiatives agreed and promoted at community level will engender real solutions." For example, his association is able to finance its projects in developing countries with financial support from private companies in rich countries. Cooper believes that only individual action is capable of bridging the gaps in political decision-making. Will it be enough? Jonathan Porritt has his doubts. "In my view, the social movements emerging at local level can have only a very marginal influence." Strahan concedes that the coming situation is rather worrying. "But I am nevertheless hoping that peak oil will engender social movements at local level to enable people to take their future in their own hands in cooperation with their neighbours."

One thing is certain: peak oil and, in the longer term, global warming will radically alter the face of our world. It is up to us to prepare for this unprecedented transition as best we can. This is how David Wasdell summarises the situation: "Two caterpillars on a cabbage leaf see a butterfly pass by. One of the caterpillars says to the other: you'll never catch me on one of those things! I believe that the world of tomorrow will be as different from our own as caterpillars are from butterflies." ●

J.P.G., J.V.R.

(1) Carrie Pottinger, Energy Technology Coordinator, IEA Energy Technology Collaboration Division.

Public Consultation of the European Commission's Directorate-General for Energy and Transport
ec.europa.eu/energy/

PUBLICATIONS

The post-oil era for the uninitiated

La face cachée du pétrole
Éric Laurent – Plon (2006).
How long will it be before the world's oil reserves start running out? Éric Laurent has scoured the world from Saudi Arabia to China to the United States seeking answers to this tricky question. His book dissects the host of geopolitical issues surrounding black gold, from the 1973 oil crisis to the collapse of the USSR to the 11 September 2001 attacks and America's invasion of Iraq.

Energy Autonomy: the economic, social and technological case for renewable energy
Hermann Scheer – Earthscan/James & James, ISBN 1-84407 (2006)
Hermann Scheer, German MP and Chairman of the *World Council for Renewable Energy*, explains how the world could achieve energy self-sufficiency.

L'énergie à l'heure des choix
Pierre Papon – Belin (2007)
This exhaustive analysis of the potential of the major non-hydrocarbon energy sectors critically appraises technology scenarios up to the year 2050.

Oil crisis
Colin J. Campbell – Multi Science Publishing (2005)
After demonstrating, more than a decade ago, that the oil crisis was imminent (*Coming Oil Crisis*, 1997), controversial geologist, C.J. Campbell, is back on the attack, proving that this much-feared crisis has indeed arrived and that the world will be hard-pressed to cope with its historic impact. The only hope is renewable energy, especially hydrogen.

Towards a post-carbon society
European Commission (2007)
European research on economic incentives and social behaviour. This publication reports on the results and conclusions of a conference held in Brussels on 24 October 2007, which was attended by more than 500 stakeholders from the public and private sectors.
ec.europa.eu/research/social-sciences/pdf/towards_post_carbon_society_en.pdf

Energy for the experts

World Energy Outlook 2007 – China and India Insights
IEA (2007)
www.worldenergyoutlook.org
Every year, *World Energy Outlook*, the International Energy Agency's flagship publication, extensively analyses medium- and long-term prospects for the world energy market. The 2007 edition undertakes an exhaustive review of the emerging markets of China and India. What impact will their energy choices have on the rest of the world?

World Energy Technology Outlook 2050 (WETO H2)
Directorate-General for Research, European Commission (2006)
ec.europa.eu/research/energy/pdf/weto-h2_en.pdf
This European study conducts a detailed analysis of the world's energy and environmental challenges in the coming 40 years. Based on two different scenarios developed using the *POLES* simulator, *WETO H2* examines the long-term impact of investment in new energy sources and of measures to reduce greenhouse gas emissions.

WEBSITES

International Energy Agency (IEA)
www.iea.org/journalists/index.asp
Made up entirely of OECD members, the IEA was created following the 1973 oil crisis. Now the mandate of the IEA's 190 officials is to balance energy policy-making worldwide by means of the 'three E's': energy security, economic development and environmental protection.

World News Network: Renewable Energy
www.renewableenergy.com
The renewable energy section of *World News Network*, a news website supplied by a host of news media and agencies, provides all the latest information on the renewable energy sector.

Association for the Study of Peak Oil & Gas (ASPO)
www.peakoil.net
This informal network of scientists was created by Colin J. Campbell, the famous geologist and expert on peak-oil issues. ASPO International is an organisation of many different national ASPO organisations. Its aim is to express independent views in a bid to determine the date and impact of the peak and decline of the world's oil and gas production.

European Wind Energy Association (EWEA)
www.ewea.org
The *European Wind Energy Association* is a non-profit non-governmental organisation made up of national associations and wind-energy companies. Its aim is to promote wind energy among the general public and decision-makers.

International Partnership for the Hydrogen Economy (IPHE)
www.iphe.net
The IPHE was created in 2003 and has 17 members, including the European Union and the United States. Its aim is to hasten the emergence of the hydrogen society by means of hydrogen-technology research, demonstrations and commercialisation.

Directorate-General for Energy and Transport
http://ec.europa.eu/dgs/energy_transport/index_en.html
What European legislation exists on energy? What research is the European Union funding? All the answers can be found on the website of the European Commission's Directorate-General for Energy and Transport, together with a mine of other energy-related information.

Solar Electric Power Association
www.solarelectricpower.org
All you need to know about the production of electricity from solar energy. This site is packed with information on photovoltaics and concentrated solar thermal energy.

World Council for Renewable Energy (WCRE)
www.wcre.de/en
In spite of widespread public support for renewable energies, current levels of investment and interest in fossil fuels and nuclear energy are a major barrier to their introduction. This was the reason for creating the WCRE in 2001 as an international lobby organisation for green energies.

EIA Kid's Page
www.eia.doe.gov/kids/energyfacts/
Where does oil come from? What are geothermics? How is electricity produced? The Kid's Page site of the United States Government Energy Information Administration (EIA) is packed with energy-related quizzes, games and information sheets. Although it is aimed at children and teachers, it is sure to be of interest to a wider public too. In English only.

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Oil traps

The Realmonte salt mine in Sicily, Italy. The sodium chloride (rock salt) appears as white layers and the potassium salts as beige. These vertical layers were formed at the time of the Messinian Salinity Crisis – a geological event that occurred around five million years ago during the late Miocene Epoch, when the Strait of Gibraltar was temporarily closed, causing the Mediterranean Sea to dry up. These layers give us an idea of the diapiric traps of the same age buried within the Earth's mantle (domes or anticlinal folds in which the dense overlying rocks have been ruptured by the squeezing out of less dense, plastic salt rock). Salt diapirs are a type of geological formation that can trap large concentrations of hydrocarbons (oil or gas).