



# Green algae as fuel factories



Photo courtesy of University of California, Berkeley

**A**nastasios Melis and Liping Zhang of the University of California at Berkeley, and Michael Siebert, Maria Ghirardi and Marc Forestier of the National Renewable Energy Laboratory (NREL) in Golden, Colorado, have shown that, in the absence of a supply of sulfur and oxygen, the green algae *Chlamydomonas reinhardtii* can switch from oxygen production to hydrogen production. A joint patent has been filed by UC Berkeley and NREL for this new technique for capturing solar energy, which was presented on 21 February at the annual meeting of the American Association for the Advancement of Science in Washington D.C. and published in the January 2000 issue of *Plant Physiology* (*Plant Physiol.*, 2000, **122**, 127-135).

Green algae normally employ the same photosynthetic process as any other plant, converting sunlight, water and carbon dioxide to chemical energy, and emitting oxygen as a waste product. It has long been known since the 1940s that after a period of darkness and in the absence of oxygen, an alternative anaerobic process catalyzed by hydrogenase kicks in, producing molecular hydrogen. The problem has been that in order for the algae to survive, illumination is required, even for the hydrogen-generating pathway. Once that happens, photosynthesis resumes, the algae start making oxygen again, and the oxygen deactivates the hydrogenase. Researchers have tried continuously purging the oxygen with inert gases, but that makes the process too expensive and impractical for large algae cultures.

Attempts to destroy the oxygen chemically have often resulted in destroying the algae as well. These stumbling blocks discouraged research into using algal cultures as a source of renewable energy.

The current advance is a way to alternate back and forth between the oxygenic and hydrogenase processes. Instead of incubating the algae culture in darkness, the metabolic switch is the removal of sulfur from the growth medium. In a stoppered bottle, the algae have no access to outside oxygen, and the absence of sulfur prevents it from producing its own by photosynthesis. Under these anaerobic conditions, a one-liter algae culture produces about 3 ml of hydrogen per hour, which bubbles to the top and is collected in tall glass tubes. After about four days of hydrogen production, the algae must be allowed to return to photosynthesis; the process can be repeated two or three days later. In their experiments, the researchers tested algae cultures through three full cycles, but believe the culture could go back and forth many more times.

The process has still to be tested in small-scale industrial and commercial operations, and larger utility photobioreactor facilities, but the new discovery opens up the possibility of harnessing nature's own tool, photosynthesis, to produce hydrogen as an alternative fuel from sunlight and water. ([http://www.urel.berkeley.edu/urel\\_1/CampusNews/PressReleases/releases/01-27-2000b.html](http://www.urel.berkeley.edu/urel_1/CampusNews/PressReleases/releases/01-27-2000b.html))

## EU chemical industry CO<sub>2</sub> emissions remain absolutely constant

Recent figures from CEFIC, the European Chemical Industry Federation, show that, in absolute terms, the industries' CO<sub>2</sub> emissions have remained fairly constant during the period 1990–1997. However in relative terms the industry has made significant strides forwards both in terms of energy efficiency and CO<sub>2</sub> releases per unit of production. Industry production output has increased by over 20% during this period but energy consumption has risen by only 6%. In relative terms CO<sub>2</sub> emissions have been gradually falling and were over 18% lower per unit of production in 1997 than in 1990 (<http://www.cefic.be/>).

## ICI to reduce mercury discharges

ICI Chlor-Chemicals has set up a Waste Brine Treatment 2000 project to reduce the amount of mercury discharged from its mercury cell chlorine plants. Planned improvements will be phased in over several years at a total cost of over £3.5M. (<http://www.chlor-chemicals.com/>)

## Paints and coatings

Two main environmental factors are currently driving innovation in the paint

and coatings sector. The phase out of tributyl tin as an antifouling additive, and the control of VOCs are both issues which are the subject of ever-tightening legislation. Some recent developments in this industrial sector are outlined here. The control of VOCs is currently the focus of the EC, and proposals for emission standards are being discussed. The likely cost of implementing the proposals (along with controls on ozone air quality standards is thought to be around EUR 7.5bn in addition to the EUR 58bn already committed (*CEPE News*, 1999, 2, 30—secretariat@cepe.org; *Farbe und Lack*, 1999, 105(11),19).

The Norwegian government has recently announced its plans to create a cleaner paints and lacquers industry by a mixture of tax penalties and outright bans on the most harmful components, and voluntary reductions in the use of other harmful components by the industry. The Government intends to involve all parties (manufacturers, dealers, consumers, and authorities) in order to encourage a more environmentally acceptable industry to evolve (*Polym., Paint, Colour J.*, 1999, 189(4422) 5).

#### **Tributyl tin phase-out**

In November, the International Maritime Organisation made the decision to phase out tin-based paints in 2003. This means that the use of paints containing tributyl tin will be banned in 2003, with a phase out ending in 2008 (*Eur. Chem. News*, 6 December 1999). Tributyl tin has been shown to cause marine pollution, and was banned on ships over 25m length in 1987. However, 85% of ships worldwide still use tributyl tin as an anti-fouling additive, and its ban will have significant repercussions on the paint industry in India, where tributyl tin paints still account for 5% of the total market (*Chem. Weekly*, 1999, 45(16), 74). This decision was made on the basis that suitable alternative paints are available.

The Japanese company NOF have announced that their tin-free paints will now be marketed globally (*Eur. Paint Resin News*, 1999, 37(11), 14). The paints are based on silylated monomers (silyl acrylate and methacrylate, and sales are expected to reach 10000 tonnes per annum.

Specialty chemicals manufacturer Rohm and Haas Company based in Philadelphia, Pennsylvania, is one company that has developed an alternative to tributyltin in marine paints for large commercial vessels. SEA-NINE® 211 marine antifoulant employs isothiazolone chemistry as a more

environmentally acceptable ingredient in marine paints. The new marine antifouling agent was rewarded with the "Green Chemistry Challenge Award" from the U.S. Environmental Protection Agency in 1996. The company has just completed a modernisation of its site in Jarrow, UK, which produces these compounds. Improvements include equipment to reduce emissions into air and water.

#### **Water-based paints and coating resins**

Two Japanese companies have announced that they have developed water-based products to replace solvent-based paint and coating systems. Toyota has devised a new technology which allows them to use water-based paints on their cars (*Eur. Paint Resin News*, 1999, 37(10), 14). The technology is in place at the company's factory in Takaoka, and has resulted in a reduction in VOC emissions of 50%. This makes Toyota the first Japanese car manufacturer to use water-based paint technology (<http://www.toyota.com/>).

Nippon Kasei has also developed a water-based coating resin, based on three co-monomers—dimethylol butyrate, dimethylol propionic acid and diacetone acrylamide. All three monomers will be produced at a new facility in Onahama (*Eur. Paint Resin News*, 1999, 37(11), 14). The products will be launched soon in Western markets.

#### **Greener green**

Heubach GmbH has announced that it will build a second plant to produce its phthalocyanine green pigment in India on a 3000 tonnes per year scale (*Eur. Paint Resin News*, 1999, 37(10) 5). The plant will incorporate new technology to reduce the quantity of solid waste produced.

## **Shell takes steps to cut emissions**

Mark Moody-Stuart, Group Managing Director of Anglo-Dutch oil major the Royal Dutch/Shell Group highlighted the companies commitment to climate care and wider issues of sustainability during his opening speech at the World Economic Forum in Davos in January. "Shell companies believe that the best approach to climate care is to make it part of a sound business rational, and that a strong commitment to a sustainable future is the best basis for a sound business," he said.

Although Shell International Renewables is looking at commercially

viable opportunities for solar cells, biomass and wind power, Moody-Stuart believes that hydrocarbon energy sources will still have a major role for most of the 21st century. The commercial viability for renewable energy sources, on the scale needed to make a significant impact, is still many years away.

Shell have been working towards meeting the objectives set up under the Kyoto protocol and recently launched an internal trading system to help meet greenhouse gas emission reduction targets. The Shell Tradeable Emission Permit System (STEPS) will help the group meet an overall 10 percent cut in greenhouse gas emissions by 2002 compared with 1990 levels. Mark Moody-Stuart said "STEPS is going to be a key factor in reaching or exceeding the emissions reduction targets we have set ourselves."

The system will allow group businesses involved in chemicals, refining and exploration and production as well as in different countries to trade permits worth 100 tonnes of carbon dioxide or methane equivalent over an internal web site.

Each business unit will be able to buy or sell permits over the next three years to hit a two percent reduction target from 1998 emissions levels, the last available date for data. The system will work similarly to the Kyoto Protocol proposals whereby units succeeding in cutting emissions would be able to sell them to those not so successful.

Emissions covered by STEPS make up 30% of the Group's total emissions. Chemicals, refining and exploration and production businesses, from North America, Europe and Australia, are all represented in the system.

Further information about STEPS can be found at <http://www.shell.com/steps>

Shell is also involved in a consortium called Blyth Offshore Wind Limited to raise two of the world's most powerful wind turbines off the UK north east coast. The turbines, each of two Megawatt-capacity (enough in total to power 3000 average households), will be the largest erected offshore in the world and the first to be built in such a demanding position, subject to the full forces of the North Sea. First electricity is expected to be generated in August 2000.

## **Improvements in packaging**

Improvements in packaging have led to reductions in waste production. For



example, a survey by the Association of Plastics Manufacturers in Europe (APME) has shown that plastic packaging has been reduced in weight by 28% in the decade ending in 1997. This is predominantly through improvements in the performance (*High Perform. Plast.*, 11 November 1999, 8) which have allowed better levels of performance, and thus reduced weights of plastic. The major reductions have been achieved in palletizing films, where a remarkable 73% reduction in thickness has been achieved.

AgrEvo of Germany has just won an award for environmental protection for a new packaging system for some of its pesticides. The system is aimed at avoiding spills during application of the pesticides of farms. The company was also commended for its waste management scheme, where users can return used packaging.

The German Packaging Federation (IVP) has proposed a new autodisposal system which it claims will be cheaper to run than the current Green Point system. A proposal produced in consultation with the Recycling Association (VfW) could lead to a reduction in cost for recycling of, for example, 1000 polythene bags from DM58.66 to DM36.89

Degradable plastics are making inroads in China (*China Chem. Reporter*, 1999, 10(37) 9–11). Over 100 facilities now exist in China for the production of such plastics, with the capacity to produce 20,000–30,000 tonnes per year of products derived from degradable plastics. While this is still small compared to the total amount of plastic produced (*ca.* 15 M tonnes p.a.) it is a growing part of the market. The necessity for such changes is underlined by the 2 M tonnes of hard-to-recover plastic waste which is predicted for this year.

## Renewable plastics

The production of polymers from renewable resources is an area of continued activity, although several processes have been proven technically, production economics have prevented wide scale commercialisation.

Dow Chemical and Cargill (as the joint venture company CPD) believe they have found the solution and have recently announced their intention to build a large scale 'renewable plastics'. Called NatureWorks, the technology allows the company to process natural plant sugars from crops such as corn and wheat and rice, rather than traditional petroleum

based materials, into polylactide polymers (PLA). The first plant (14,000 te) is to be built in Nebraska as part of a \$300 million investment business. A further plant is also being planned for Europe within the next few years (<http://www.cdply.com/natureworks/default.asp>).

One of the main applications of the polymer will be in fibres for clothing where attributes such as wrinkle resistance and good moisture management properties together with its compatibility with downstream processing equipment should ensure success. Other potential applications for the polymer include carpets and food containers.

The key elements of the process involve fermentation of unrefined dextrose, obtained from the crop, to lactic acid. This undergoes a condensation process to produce a cyclic dimer intermediate which is purified by distillation. The final step involves a ring opening polymerisation in a solvent free melt, conditions of this process can be varied to produce a range of molecular weights and crystallinities. It is this novel manipulation of polymer properties which CPD will ensure the success of the project, enabling the product to be sold into a variety of markets.

Other green credentials of the product are that it is fully compostable and that 30% less fossil fuels are required to produce it than with conventional plastics (<http://www.cdply.com/home.asp>).

## Making money from old diapers (nappies)

The waste recycling company Knowaste have opened a \$20M plant in Arnhem to recycle diapers and adult incontinence products. The local waste disposal costs of \$150–400 a ton allow for a profit to be made on the recycling process. Ironically the company had earlier found it impossible to make a profit in the North American market. When they started in Ontario, Canada 10 years ago the company flourished thanks to the policies of the then Socialist Government who raised landfill dumping fees to encourage recycling. Since then free market policies have dominated and Knowaste have been unable to compete. The new owners of Knowaste sought new business opportunities in Boston and San Francisco but again could not make their processes competitive with local dumping. Fresh from their new success in Europe

Knowaste is planning to take on the North American market with a new lower-cost diaper recycling process. This relies on the deactivation of the super adsorbing polymer from the pulp which it can then sell to paper companies. A new plant will soon begin operating in Mississauga where it will service a local residential operation that delivers disposable diapers and then takes them away for a fee. It is competitive with local landfill despite these being only \$50 a ton. Further developments in the US are planned (<http://www.knowaste.com/>).

## Pollution

### *Ozone in the European Union*

The EU report for 1999 shows that despite a small reduction in Central Europe there is still not a global reduction in population and ecosystems exposure to ozone in the Union. The main points in the report concern peoples health, and protection of the vegetation. In 1998 the indicative ceiling of 110 micrograms per cubic meter during 8 hours was on average exceeded during a 20–60 day period in Mediterranean countries and by 10–35 times in countries located in the centre of the Union. The danger level of 360 micrograms per cubic meter was exceeded several times in Greece, Italy and France. In 1999 no exceeding of the danger level occurred but the ceiling for informing the public (180 micrograms per cubic meter during an hour) was exceeded by all member countries except Ireland, Denmark, Sweden and Finland. The most critical occurrences were in France, Greece, Italy and Spain where the population was informed of the high ozone levels during a 40–60 day period. The vegetation limit has been established at 200 micrograms per cubic meter and this was exceeded for more than 200 days in 94 separate observation posts located in 13 member states.

### *Contrary pollution levels in the UK*

While pollution in the UK is falling, the level throughout the UK is rising dramatically. A report from Friends of the Earth shows the biggest deterioration in air quality since modern records began. The number of days on which pollution broke health standards rose by 20% in cities and by 53% in the countryside compared with 1998. In North and Mid-Scotland and North Yorkshire, the number of days of moderate or high pollution has risen by 50% in 3 years

largely due to increased levels of traffic. The Department of Health in the UK says that in London the health costs of pollution are very low—only 0.2% of the health budget compared to 2% in dealing with road accidents. They also point out that lead emissions have been almost eliminated, sulfur dioxide and particulates have fallen dramatically and ozone levels are lower in London than in most other parts of the country despite heavier traffic. A report “Transport and Health in London” produced for the Department of Health has concluded that “The efforts now in progress at national and local level to introduce national air quality standards and to put in place low-emission zones (from which heavily polluting vehicles are barred) do not appear to have been given a justification on grounds of saved health costs” (*Reuters News Service*, January 2000; *The Independent*, 17 January 2000).

## New developments in catalysis

News relating to enzymatic methods involves the polymerisation of natural products such as syringic acid and cardanol (*CHEMTECH*, 1999, **29**(10), 22–28). Japanese workers have used the oxidative polymerisation of these materials to produce polyphenolic resins, which are normally produced using toxic monomers such as formaldehyde. Reaction conditions are mild, and the process generates relatively benign waste streams.

Improvements in titanium dioxide photocatalysts have also been reported. Ecodevice of Tokyo has developed a new photocatalysts which can absorb and use visible light as well as UV (*Jpn. Chem. Week*, **40**(2049), 3). The new material can use 50% of solar energy, compared to the 5% which is amenable to existing photocatalysts. The company is currently planning to build a plant to exploit the breakthrough.

A second report on photocatalysis (*CHEMTECH*, 1999, **29**(10), 55) indicates the potential of photocatalytic process for the destruction of pollutants in waste water.

Wako Pure Chemi has announced the commercialisation of a new range of encapsulated catalysts (*Jpn. Chem. Week*, **40**(2050), 3). These new catalysts are based on the microencapsulation of *e.g.* osmium tetroxide or scandium triflate in polystyrene matrices. The encapsulated

materials often have remarkable chemical and catalytic properties, but are difficult to handle and recover. The new materials circumvent these difficulties. The commercialisation of these materials follows on from articles written by Shu Kobayashi and his group in the last year or two (S. Kobayashi and S. Nagayama, *J. Am. Chem. Soc.*, 1998, **120**, 2985).

As reported in a recent issue of *Catalysis Today*, researchers at Ohio State University have developed a new method to remove toxic nitric oxide emissions from stack gases. With the help of a palladium-based catalysis methane reacts with the nitric oxide to form nitrogen, carbon dioxide and water. Work is proceeding to improve the formulation of the catalyst, especially to minimise inactivation by sulfur dioxide present in flue gases (<http://www.acs.ohio-state.edu>).

## Cleaner cars

*Clean cars a step nearer* (see *Green Chem.*, 2000, **2**, G9)

Cars and trucks that run on a combination of electricity and other fuels—known as hybrids—could comprise 20 percent of vehicle sales by 2010, William Clay Ford Jr., chairman of Ford Motor Co, said recently. But Ford predicted that both hybrids and vehicles powered by traditional internal combustion engines will eventually be replaced by clean-burning fuel cell engines.

“It’s going to be a winning situation all the way around—consumers will get an efficient power source, communities will

get zero emissions, and automakers will get another major business opportunity—a growth opportunity,” Ford said.

Automakers have been introducing more electric and alternative fuel vehicles in the last few years as they experiment with new ways to build more efficient engines.

Hybrids now make up a tiny fraction of vehicles sold. Toyota Motor Corp and Honda Motor Co. Ltd currently sell hybrid vehicles in Japan, and are expected to start sales in the United States early this year. Ford Motor, General Motors Corp and DaimlerChrysler AG are scheduled to introduce hybrid vehicles that get 80 miles per gallon by 2003 as part of a U.S. government-sponsored programme (*Reuters News Service*, January 2000).

## Western Australia leads new cleaner fuel regulations

Western Australia has introduced new tougher cleaner fuel standards ahead of the rest of the country. Leaded fuel has been replaced with a new fuel containing an additive substitute. Additionally the permissible sulfur level has been reduced from 5000 ppm to 500 ppm for some parts of the state with the rest following by 2001. The federal Government has ruled that refineries nationally must produce diesel fuel with a sulfur level of only 500 ppm by the end of 2002 and 50 ppm by January 2006. The industry average is currently *ca.* 1300 ppm (*Reuters News Service*, January 2000).

## Hybrid-electric car for Australia

A new hybrid-electric car, the aXcessaustralia has been developed by CSIRO’s Australian Automotive



*The aXcessaustralia car. The drive motor and transmission are at the front. In the rear is the internal combustion engine surrounded by the supercapacitor pack. The battery pack is located underneath the rear seats. Photo courtesy of CSIRO, Australia.*



Technology Centre (AATC) and will be launched in June 2000. The aXcessaustralia car uses a novel, compact internal combustion engine to drive a CSIRO Generator in a Series hybrid configuration. The Surge Power Unit comprises CSIRO supercapacitors and CSIRO batteries. The traction motor is a CSIRO water-cooled electric motor that also acts as a generator when braking. During most of the operating time, power is supplied from the batteries, supplemented by the supercapacitors for acceleration. The internal combustion engine generally operates in response to the needs of the storage system. However, for extreme power needs, all three sources of energy are available to the drive motor enabling vehicle performance to be equivalent to a conventional car. The aXcessaustralia will reduce fuel consumption by half and lead to a 90% reduction in greenhouse gas emissions.

The supercapacitors, which use a carbon coating in an organic electrolyte to form what is termed a 'double layer capacitor', absorb energy and deliver stored energy very quickly, while battery pack provides enough energy storage to allow the car to complete an urban drive cycle under electric power only. This means that the car gives the range and performance and low emissions of other hybrid cars, but also will run in zero-emission, all-electric mode in areas that are particularly environmentally sensitive such as city centres. In this way the aXcessaustralia car combines the performance and very good emissions of other hybrid vehicles with the zero emission of an electric vehicle. The car can also be charged overnight on low tariff electricity to reduce running costs further (<http://www.csiro.au>).

#### **Nissan claims cleanest gasoline car**

The Japanese car manufacturer Nissan has claimed the worlds cleanest gasoline driven car, the Sentra CA. They say that the emissions from the car after a 16KM drive are less than from a normal car standing on a drive all day (cars still emit vapours after the engine is turned off or due to heating from the sun). The car has been given "super ultra low emission" status by the Californian authorities but unlike the Honda Accord, it has also been given partial zero emission credits. California requires that 10% of all vehicles sold in 2003 should be "zero emission". The Sentra will initially only be sold in California which is the only US state to offer low sulfur gasoline (<http://www.nissan-na.com/>).

## **Sustainable development in hard surface cleaners**

Unilever believes that, for the detergents industry to be sustainable, it must raise its resource conservation by a factor of 4, meaning a 75% reduction in resource consumption for any unit of production. The European Detergent Association (AISE) has established a code of practice with four key objectives to be reached over a 5-year period beginning from the base year of 1997. Among these are targets for energy savings, reduction of product consumption, reduction of packaging consumption and biodegradability. According to life cycle studies, much of the environmental impact of laundry detergents is in their use and subsequent disposal. Chlorinated solvents are effective cleaners and are non-flammable, but they are increasingly the subject of strict environmental standards and this is a challenge for hard surface cleaners that involve environmental indicators for a more sustainable approach to chemical production and use. These indicators include ozone depletion potential, global warming potential, presence of volatile organic compounds, toxicity, and reactivity. Consequently water-based cleaning formulations are being marketed by companies such as Alconox, Northern Products, Watson Technical, and Safe Science.

## **A new method to recover metal from acid wastes**

MARS Technology Inc has proposed a new two-stage process to recover metal from acid waste. The process is environmentally friendly since it offers an alternative to deep well disposal and can recover useful metal salts from hydrochloric acid solutions that can be purified into chemical commodities. Metal chlorides are absorbed in a standard ion exchange resin in a column and then stripped by a patented system that uses tap water.

## **Phytoremediation**

Crabgrass, a plant considered a noxious weed by gardeners, is being investigated at dozens of US institutions as a means to clean up sites contaminated with hydrocarbons. Scientists at the University

of Washington and Washington State University have developed hybrid poplar trees which extract the widely used solvent trichloroethylene, breaking it down into harmless compounds. Sunflowers have also been used to remove radioactive contaminants from a pond of water near Chernobyl, and the US Army is investigating several plants to extract explosive compounds, including TNT from several test sites. For general information and a large number of weblinks on phytoremediation see <http://www.engg.ksu.edu/HSRC/phytoem/home.html>.

## **A cheaper and greener way to make nylon**

RPC Inc. and Fluor Daniel are making a new cost-effective and environmentally friendly nylon 66 production technology available. Oxygen and a cobalt catalyst are used to oxidize cyclohexane to adipic acid. The production of cyclohexanone and cyclohexanol by-products is limited. Nitric acid is not involved, so there are no NOx emissions and no nitrates produced; raw material costs are reduced. An analysis comparing a theoretical unit with an existing unit (both 135,000 tonnes/y) indicated potential capital cost reductions of over 30% and operating cost reductions of 20%.

## **Adhesives**

### *Europe – The Solvent Emissions Directive*

In March 1999 the Solvent Emissions directive was adopted by the European Council of Ministers and should be implemented by member states within 2 years. The adhesives industry uses about 130,000 tonnes/y of solvents in its products and has a major part to play in meeting the Directive's target, both in the production of adhesives and their application by adhesive coaters. The principal objective of the legislation is to limit volatile organic compound (VOC) emissions from solvents from industrial sources. It is expected that the Solvent Emissions directive will reduce overall emission of VOCs in 2007 to 67% of the 1990 level. All adhesive coaters using more than 5 tonnes/y of solvent are covered by the Directive. A table shows the requirements as set out in the directive for the adhesive industry. There are two bands of solvents use considered: 5–15

tonnes/y and more than 15 tonnes/y. Coating of leather and footwear manufacture have specific limits in the Directive. Also affected are adhesive manufacturers using more than 100 tonnes/y of solvents. The principal impact on the industry arises through compliance. Instead of restricting the use of specific solvents, the Directive allows the user the flexibility to reduce emissions through abatement or use of alternative technologies or a combination of both. Among the options are an Emissions Limits Option, a Reduction Scheme Option, and a National Plan. A second table gives the selection criteria for choice of adhesive.

#### **North America – switching to water-based adhesives**

According to the Pacific Northwest Pollution Prevention Resource Center, there are many issues involved in switching from solvent-based adhesives to water-based systems. The successful application of new adhesive technology requires the input of multiple decision-makers, especially product development engineers, adhesive suppliers, application equipment vendors, and end-product customers. The overall quality required for the product being produced is ultimately determined by the customers. Some of the most important issues regarding water-based adhesives are: performance requirements including bond strength, process adaptability, and durability; application issues; mixing options; and curing technology. There are numerous advantages of water-based adhesive technologies over solvent-based adhesives. The principal advantages include the removal of hazardous air pollutants and volatile organic compounds from the process; a complete removal of explosion risk; and the reduced generation of hazardous waste. The limitations include the need for an oven to cure the adhesive which takes up space and possibly increases energy costs; increased generation of wastewater and sludge; more stringent production run requirements; and a limitation on complete substitution of water-based adhesives for solvent-based adhesives.

## **Cleaner fuels**

#### **Methanol fuel**

In experiments that combine methane photolysis and catalytic photolysis of water, methane and water have been

converted to methanol, hydrogen, and acetic acid by a doped semiconductor photocatalyst (platinum-doped tungsten oxide) at temperatures of ~94 °C and at atmospheric pressure. The reaction was enhanced in the presence of hydrogen peroxide, which is consistent with the postulated mechanism that invokes a hydroxyl radical as an intermediate in the reaction sequence. Such that the hydroxyl radical reacts with a methane molecule to produce a methyl radical and the methyl radical then reacts with an additional water molecule to produce methanol and hydrogen. Experiments also indicate that the photocatalyst operates under visible light rather than UV (*New developments in the photocatalytic conversion of methane to methanol*, *Catal. Today*, 2000, **55**(3), 259-267).

#### **Fuel cells**

Global Thermoelectric Inc. have announced a new prototype fuel cell aimed at the residential market using natural gas as its energy source. It is also developing manufacturing facilities in Calgary, Canada. The successful test of the design using natural gas will allow development of power systems in the 1–5 KW range to supply electricity and heat in homes or in remote industrial locations. It hopes to begin remote system testing in early 2001. Another fuel cell company Ballard Power Systems Inc announced in January an agreement with Tokyo Gas Co. Ltd. and Ebara Corp to develop one KW fuel cell cogeneration systems for residential use in Japan (<http://www.globalte.com/>).

#### **Funding for clean fuels**

The US Energy department is to provide \$75 million in research grants to develop clean fuels and better pollution control devices for cars and trucks. The research money is part of the government's efforts to cut sulfur levels in gasoline. In December the administration proposed new regulations requiring the nations refineries to reduce sulfur levels in gasoline to an average 30 ppm by 2005 (current levels are at *ca.* 300 ppm). The Department is asking for proposals in the following areas:

- the production of clean fuels from different energy sources—crude oil, petroleum coke, refinery waste, natural gas or coal
- innovative emission control systems and verification in engine tests
- new fuel making processes or technologies that refineries and

automakers could use in future fuel, engine and emission control systems

Funding will be available from 2000 to 2005 and will require participants in the research to share 35–50% of the cost of each project. The Department will evaluate proposals over two time periods: those received by 1 June 2000 and those received by 1 December 2000 (*Reuters News Service*, February 2000)

#### **Washington court rules out EPA extension of reformulated gasoline rule**

A US court has ruled that the EPA cannot extend its rule on the use of reformulated gasoline to areas with little or no pollution problems. Reformulated gasoline contains additives that increase the oxygen content of fuel so that it burns more completely thereby reducing air pollutants. The American Petroleum Institute and the National Petrochemical and refiners Association claimed that the EPA exceeded its authority in September 1998 when it issued the rule opening the program to more communities. The US Court of Appeals for the District of Columbia agreed that the EPA exceeded its statutory authority and ordered a review. The API have stated that they support clean fuels “based on need, sound science and cost effectiveness” (*Reuters News Service*, January 2000).

#### **Soybean fuel additives**

Researchers from the University of Kansas in the USA have shown that fuel additives made from soybean oil improve the performance of diesel fuel and, in particular, of diesel fuel containing ethanol (so-called ‘diesehol’). Using a blend of 10% ethanol and 90% diesel in a Volkswagen test engine, it was found that the soybean-oil based cetane improvers reduced the amount of particulate matter in the engine by more than 30–50% compared with unblended diesel (<http://www.ukans.edu>).

#### **US farmers push for ethanol to replace MTBE**

US farmers are pushing the government to replace the controversial oxygenate MTBE with ethanol in California's clean burning gasoline program. In the US most ethanol is made from corn and farmers see a huge new market in California with the State concerned over the effect of MTBE on water quality. The EPA has classified MTBE as a potential human carcinogen. However, California argues that the use of ethanol will increase emissions and cost compared to other



blends of reformulated gasoline it could make without oxygenates. It is seeking a waiver from the federal requirement that all reformulated gasoline must contain at least 2% oxygen. The EPA is currently considering this request (*Reuters News Service*, February 2000).

#### **Unleaded gasoline phaseout in the Philippines**

Manila is to phaseout leaded gasoline by April 2000, 9 months ahead of the original schedule set out in the 1999 Clean Air Act. The first unleaded gasoline was sold in the Philippines in 1994 but sales had initially been poor due to a public perception that the fuel gave lower power. Reduced taxation on unleaded fuel has however helped to remedy this and sales of unleaded fuel now amount to 45% of the total across the nation. The law has stipulated that all gasoline sold in the Philippines from 2003 must contain no more than 35% aromatics and 2% benzene so as to reduce airborne pollution (*Reuters News Service*, January 2000).

#### **California adopts gasoline rules banning MTBE**

The California Air Resources Board has brought in regulations which will ban the use of methyl tertiary butyl ether (MTBE) in fuel after 31 Dec 2002. The addition of oxygenates to gasoline had been required as part of the Clean Air Act in areas which could not meet air quality standards. However, the environmental impact outweighs air quality improvements. Under the new rules, refiners will have to cut the level of sulfur in fuel. Changes in distillation standards will allow refiners to substitute MTBE with other additives.

#### **German accord on lower sulfur in gasoline**

Germany has approved tax concessions for producers of low-sulfur fuels in a move that will raise the pressure for stricter regulations on the sulfur content of gasoline throughout Europe. German motorists will receive concessions for clean fuels, first at 50 ppm, in keeping with the EU's Auto-Oil proposals, and then at 10 ppm, well under any formally agreed limit. The shift toward ultra low levels of sulfur in German gasoline appears to be all one way. The government has declared its position with the new tax laws and the automobile manufacturers are keen to see as little sulfur as possible at the fuel pump. German refiners are also cooperating. For

example, refiners DEA and Veba Oel both say they will support the 10 ppm level. It is still possible however that the support for the lower level of sulfur might bring long term benefits to some refiners already committed to large investment projects involving sulfur removal technology when other cannot afford to follow the trend under pressure. With effect from 1 November 2001, the German oil industry will voluntarily introduce gasoline with 50 ppm sulfur at all their pumps. In exchange, the German government will introduce a DM 0.03/litre tax concession. Veba says its refineries would be ready to deliver gasoline with 10 ppm in 2002. The German government, however, must convince the European council of finance ministers that it had the right to introduce a further tax incentive to support the additional reduction.

#### **New clean air technologies for the automotive sector**

According to developers, two catalyst systems for car exhausts are unaffected by the level of sulfur in fuel. A division of the UK's AEA Technology has revealed a diesel particulate filter that utilises a low temperature plasma for self-cleaning. Delphi Automotive Systems, US, announced a device that performs partial oxidation of nitric oxide to nitrogen dioxide followed by catalytic conversion to nitrogen with reduced levels of diesel particulates and hydrocarbons. The Delphi system applies to diesel, lean-burn and direct injection gasoline engines.

#### **Sulfur silanes for green tyres**

From 1999-2002, \$106 M is to be invested by Degussa-Huels to expand its production capacity for organofunctional sulfur silanes which are compounded with rubber used for production of so-called green tyres with low rolling resistance. A production unit is to be built at Antwerp, Belgium. Global capacity will be increased by two-thirds. Capacity is also being increased at an existing facility in Antwerp and at its facilities in Mobile, AL. In Termoli, Italy, capacity for organofunctional sulfur silanes is to be more than doubled by CK Witco, at a cost of \$50 M. Completion is due by mid 2001. 17% of passenger car tyres now manufactured are green, and there has been a 10%/y increase in the use of silica-based compounds in tyres.

#### **Potential 'breakthrough' battery technology**

Exide Corp has acquired a controlling interest in Lion Compact Energy, a privately held company conducting research in dual-graphite battery technology that could dramatically advance the search for cleaner, less expensive and more efficient batteries. Under the terms of the acquisition, Exide paid \$3.5 M in cash upon closing and could pay \$11.5 M, plus certain royalty fees, over the next several years depending upon the performance of Lion Compact Energy and its product. Lion Compact Energy has thus far produced several prototype batteries using graphite in different forms as the electrode material. Exide Corp, with revenues of about \$2.4 bn/y and operations in 19 countries, is the world's largest manufacturer of automotive and industrial lead-acid batteries (<http://www.exideworld.com>)

#### **Fuel cell advance**

Researchers at the University of Pennsylvania led by Professor Raymond Gorte say that they have devised a fuel cell that uses a compound of copper and cerium oxide. Currently fossil fuels must be converted to hydrogen before fuel cells can be used, otherwise the cell is choked by carbon deposits. The new dry hydrocarbon fuel cell eliminates the wasteful conversion to hydrogen and resolving the carbon deposit problem. Tested on ethane and butane, the new fuel cell produces clean power, and emits only water and tiny amounts of carbon dioxide. This new development, reported in *Nature*, 2000, **404**, 265, opens up the possibility of smaller, cheaper and more efficient fuel cells for applications in homes and cars.

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