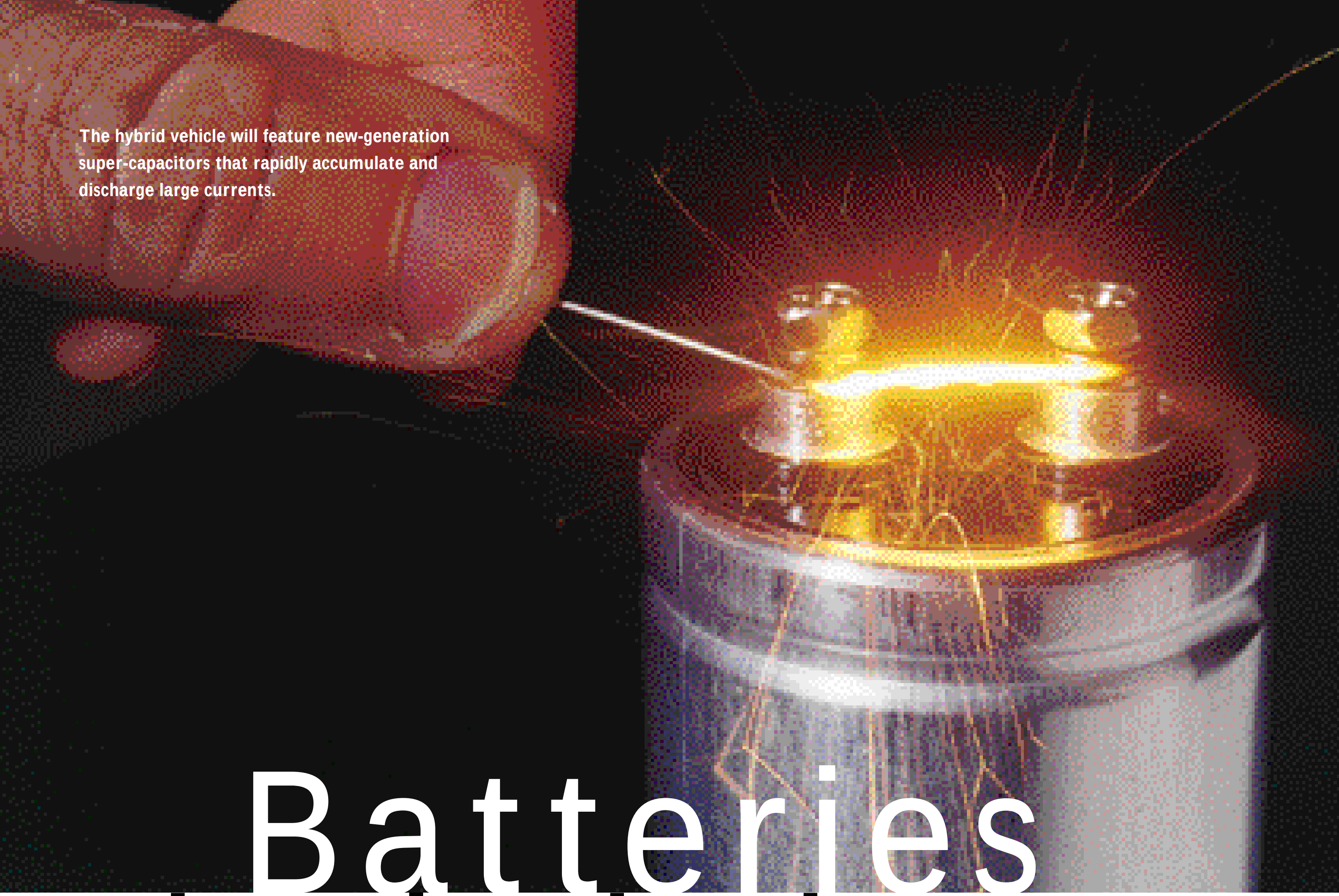


The hybrid vehicle will feature new-generation super-capacitors that rapidly accumulate and discharge large currents.

Batteries included

On the smell of an oily rag, Australian scientists are marrying battery and petrol power with a view to lifting energy efficiency, cutting emissions and injecting the motor vehicle industry with homegrown expertise. Graeme O'Neill reports.

Plant and animal breeders have long recognised a phenomenon called hybrid vigour: interbreed two related species, and their offspring will outperform either parent. The mule, for example, combines the hardiness and endurance of an ass with the strength of a horse. In a past age, these traits saw mules serve the dual role of beast of burden and occasional power source for the farmer's buggy.

The day of the mule has passed. In the 20th century, farmers drive tractors, and many of us enjoy personalised transport. But near century's end, the unbridled success of the internal combustion engine has caused serious health problems in many cities: clogged arteries, breathing difficulties, and vistas clouded by the brown haze of photochemical smog.

While stringent anti-pollution legislation has greatly reduced vehicle exhaust emissions, the sheer number of vehicles in major cities has thwarted the quest for cleaner air. So researchers in the United States, Japan and Europe and, now, in Australia, have sought a novel solution: a latter-day mule, the hybrid offspring of two different technologies – the internal combustion engine and the battery-powered electric motor.

In Japan, where high fuel prices increased the incentive to develop an alternative to the internal combustion engine (ICE) vehicle, the Toyota Motor Company has launched a compact hybrid petrol-electric vehicle, the Prius, and is selling about 2000 vehicles a month. In the US and Europe, governments are investing tens of millions of dollars in taxpayer-funded grants, boosting the major car companies' own research and development programs, which collectively are worth hundreds of millions of dollars.

In such company, Australia is a minnow among whales, but is mounting its own ambitious research to capitalise on advanced technologies developed by CSIRO. These technologies are 'highly relevant' to the concept of a hybrid petrol-electric vehicle, according to chairman of Australian Concept Car Ltd and director of CSIRO's Australian Automotive Technology Centre, David Lamb.

CSIRO and the Australian automotive parts industry have already completed one successful partnership, a project to develop a one-off Australian concept car, the aXcess, as a mobile showcase for the industry's manufacturing and service capabilities. Designed by Millard Design Australia, the aXcess car represents a blend of existing technologies and those that will be commercially available in three to five years. It is being exhibited at automotive trade shows in the US, Asia and Europe.

CSIRO is investing $6.5 million in research and development for the new hybrid ICE-electric vehicle. In the next five years, CSIRO's contribution will be complemented by Australia's automotive parts industry, so that the prototype vehicle will eventually represent an investment approaching $30 million.

The ICE-electric vehicle will itself be a stepping stone to an even more radical vehicle, powered by the compact ceramic fuel cell being developed by Melbourne-based high-technology company Ceramic Fuel Cells Ltd. Ceramic fuel cells will convert chemical energy, in the form of natural gas or hydrogen, directly into electrical energy to power an electric vehicle (see *Ecos* 93).

According to Lamb, the imperative for the project is the undertaking by industrialised nations to reduce greenhouse gas emissions, particularly carbon dioxide and nitrous oxides. But the project also represents an opportunity for Australia to develop the technological and manufacturing skills required to be a significant player in the emerging international market for hybrid ICE-electric vehicles.

'In 1963 Australia exported more vehicles and automotive products than Japan, but then pulled out of the race,' Lamb says. 'We only woke up again a decade ago, but since then we have been growing nicely.

'Under the Button Plan, the Australian automotive products and components export industry has grown from virtually nothing to $2.7 billion a year since 1985.

'The industry now offsets some of the cost of the vehicles we import, but rather than sit on our hands and wait to import hybrid vehicles such as the Prius, we want to show the Australian public and government that we can play a useful role.'

The technologies and services that CSIRO brings to the project include:

- High-efficiency electric motors based on rare-earth permanent magnets that have been proven in the Australian-built Aurora solar car in the 1997 Darwin-Adelaide international solar car race.
- Lead-acid batteries that provide greater specific energies than conventional types.
- New-generation super-capacitors that can rapidly accumulate and discharge large currents and will provide similar performance characteristics to existing ICE-powered cars.
- Expertise in electronic control systems, and in system integration.
- Expertise in systems engineering and in analysis of the total energy inputs and outputs involved in manufacturing and operating a hybrid vehicle.
- Expertise in design and casting of low-mass metal components, for weight reduction.
- Expertise in developing high-strength, low-mass polymer composites for racing vehicles, which is also applicable to lightweight vehicle design.

The final mix of technologies has yet to be decided; the project is still in the planning phase, and it is no easy matter to choose an optimal configuration. But some parameters virtually set themselves. For example, Lamb says the vehicle will be compact, and weigh less than a tonne, and its primary power source will be a petrol motor of no more than one-litre capacity.

The final package is constrained by the need to minimise weight and maximise energy efficiency and refuelling range. The law of diminishing returns means that the heavier the vehicle, the larger the batteries and super-capacitors required, and the more energy will be squandered just on lugging these heavy components around.

But at the same time, says Lamb, the vehicle must reproduce the familiar performance characteristics of conventional-engined vehicles. It must provide enough power, at least in brief bursts, for brisk acceleration in stop-start commuter driving or emergencies, as well as adequate economy for long-haul inter-city trips at highway speeds.

'It's a balancing act, but we'll probably need to draw about 40% of the vehicle's power from storage,' he says.

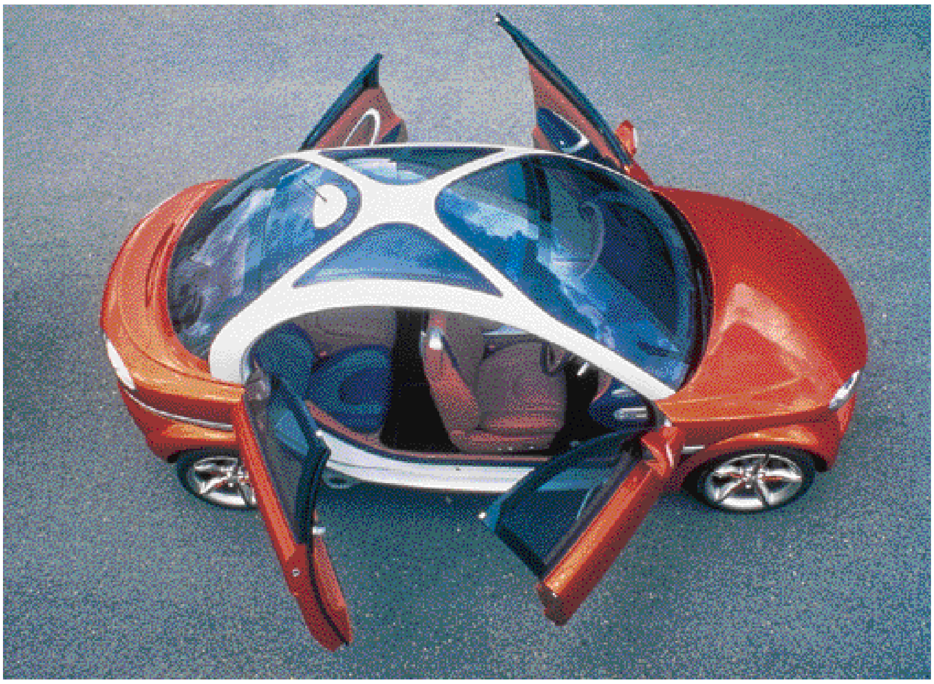
Lamb says that in conventional vehicles engine capacity is determined not by the requirements of cruising, when an engine is operating with peak efficiency, economy and minimal emissions, but by the need for repeated cycles of acceleration from rest, when emissions are highest. Drivers rarely use all the engine power available to them.

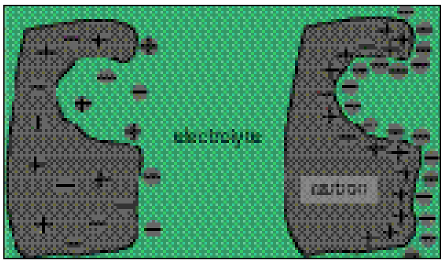
'If you run an internal combustion engine at a constant, optimal speed,

Henderson Industries

Right: The hybrid car will incorporate CSIRO expertise in design and casting of low-mass metal components, such as this die-cast magnesium seat.

Below: The aXcess car is a mobile showcase for the Australian car industry's manufacturing and service capabilities.





The super-capacitor developed by the CSIRO-capXX team incorporates activated carbon and an organic electrolyte in a process called charge separation. When the electrode is uncharged, positive and negative ions in the electrolyte are randomly distributed. When a voltage is applied, the positive and negative ions migrate to opposite electrodes, discharging the accumulated current. The super-capacitor acts somewhat like a turbo-charger for a conventional engine, providing surges of power in short bursts. It is able to deliver 50 kilowatts of power for 10 seconds.

emissions can be cut by up to 90%,' he says. So the idea is to use a small-capacity engine as a constant-output generator, which in cruise mode will rapidly recharge the lead-acid batteries and super-capacitor.

Rapid acceleration or hill climbing will quickly drain conventional batteries. The key to a viable hybrid system is the super-capacitor, which will provide bursts of power – up to 50 kilowatts – for about 10 seconds, then recharge within 10 seconds, in readiness for the next hill or traffic lights.

Ideally, the hybrid vehicle will draw primarily on stored electrical energy during urban driving, reducing exhaust emissions, and rely more heavily on its small internal combustion engine during suburban or country driving. The driver will not know which power source is being used. There will be no telltale change in the pitch of the petrol engine, only a seamless switching between the storage batteries and the capacitor.

Dr Howard Lovatt, of CSIRO Telecommunications and Industrial Physics, says the Aurora solar car employed a small, super-efficient rare-earth magnet motors to directly drive the front wheel. But the prototype hybrid is likely to have a single motor and conventional drive train, complete with differential.

Indeed, there has been no decision yet to use a rare-earth magnet motor, which would be expensive. 'Cost is no object when building a solar racing car, but we have to look for something that is cost-effective in a commercial vehicle,' he says.

The Aurora's neodymium-iron-boron magnet motors were designed to minimise two phenomena that compromise efficiency: so-called iron loss, due largely to eddy currents in changing magnetic fields, and copper loss, caused by resistance in the motor's copper windings. These losses result in heat. For a hybrid car, a compromise between efficiency and cost is necessary. A switched-reluctance motor, which exploits iron's attraction to an electromagnet, would probably serve the purpose.

Putting a small motor on the front wheel of the Aurora car eliminated friction losses normally associated with a chain or drive shaft, but such marginal gains would not be cost-effective in a commercial vehicle.

Lamb says the choice of a petrol engine is determined mainly by the need to engage a major Australian vehicle manufacturer in the project. 'We need to use components that Australian industry can supply,' he says. 'No manufacturer is going to invest in a new plant to build a special engine.'

A burst of power

The super-capacitor is being jointly developed by the CSIRO in partnership with cap-XX Pty Ltd, a high-technology Australian start-up company which is developing, manufacturing and commercialising the technology.

Dr Tony Vassallo, of CSIRO Energy Technology at Sydney, says super-capacitors provide low energy density compared with batteries, but their power capacity – their ability to deliver large amounts of power in transient bursts – is at least an order of magnitude greater than that of any battery.

The CSIRO-capXX research team has developed a world-leading super-capacitor that can deliver 50 kilowatts of power for 10 seconds. It uses an advanced proprietary design which incorporates activated carbon and an organic electrolyte that provides very high power capability.

The super-capacitor exploits a phenomenon called charge separation, in which the positive and negative ions in the electrolyte migrate to opposite electrodes; the capacitor discharges the accumulated current when a load is applied across the electrodes.

'Very high current loadings are involved,' Vassallo says. 'The wiring and switching have to be designed to cope with currents of many hundreds of amps.

'Also, unlike a battery, whose voltage remains constant as its current is drained, a capacitor's voltage drops as current is taken out, so the power management electronics have to compensate. But, unlike a battery, it means that the system instantly knows the state of charge of the capacitor.'

Vassallo says a 50 kW capacitor would probably be about the size of a small suitcase, weighing about 50 kilograms.

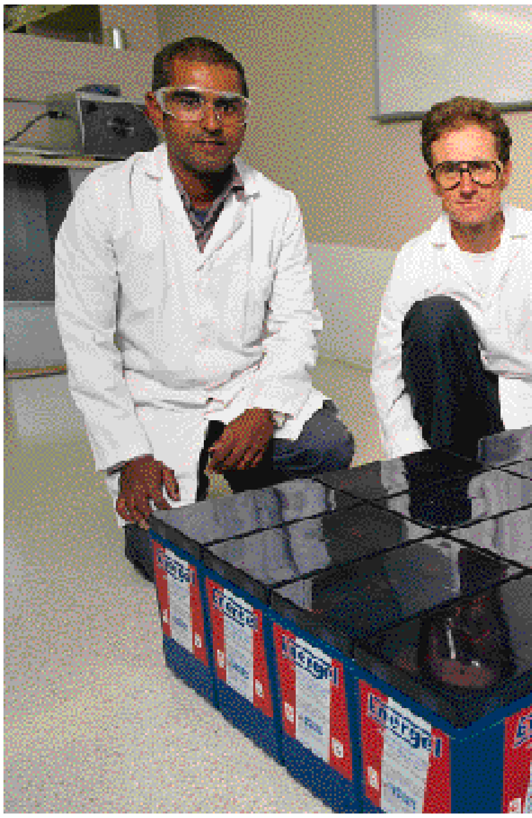
The hybrid vehicle will use advanced design lead-acid batteries, simply because no other high-technology battery can yet match this proven storage medium's combination of low cost, high power and specific energy.

Dr Russell Newnham of CSIRO Energy Technology* heads the battery development project. He is a member of Dr David Rand's Novel Battery Technologies Group, which is acknowledged as a world leader in lead-acid battery technology.

But the lead-acid batteries being developed for the hybrid vehicle will be very different from those used to power the starter motors in today's vehicles.

Newnham says the aim is to improve the power capability, specific energy and cycle-life of existing lead-acid batteries by using an innovative plate design, combined with a combination gel/AGM (absorptive glass mat) separator. The separator, whose main function is to avoid short-circuits between the plates, comprises glass-fibres surrounded with gelled-electrolyte. 'The electrolyte in such a separator is effectively immobilised,' Newnham says. 'There would be no spillage of sulfuric acid if the vehicle was involved in an accident.'

The new battery will also be capable of rapid recharging. The CSIRO team has already developed, in conjunction with the US-based Advanced Lead-Acid Battery Consortium, the technology to recharge a lead-acid battery from dead flat to fully charged within an hour, or from zero to 80% charged in under 10 minutes.



Each battery – the hybrid vehicle would use about five – would be about the size of a small conventional car starter battery. Ideally, the entire battery pack will weigh no more than 50 kg, maximising the vehicle's power-weight ratio.

The hybrid power system would require sophisticated electronics, combined with intelligent software, to ensure it operated at maximum efficiency, while delivering similar performance characteristics to a conventional ICE-powered vehicle. Again, motorists are unlikely to welcome any major change to established driving habits.

Researchers at CSIRO's Division of Telecommunications and Industrial Physics will help design the electronic control systems and write the power-management software. They will be guided by mathematical models being developed by the Division of Mathematical and Information Sciences at Sydney. Their task is to find ways of delivering energy in the required amounts, and at the right time, for everyday driving.

The modelling team is also developing models to simulate changes in urban airsheds when hybrid vehicles take to the roads. There is little point in developing a hybrid vehicle if its manufacture was to generate similar levels of air pollution to those saved in exhaust emissions.

A Melbourne-based research team led by Dr Warren Thorpe of CSIRO Manufacturing Science and Technology's Casting and Alloys Research Program will develop lightweight components for the hybrid vehicle. The program involves some 50 scientists and engineers working in the field of light alloys casting.

Thorpe says the work is aimed at the efficient use of Australia's light metals and alloys, particularly in the automotive industry, where they play an important role in making vehicles lighter and fuel efficient.

The program's Design and Prototyping Service is run by CSIRO within the CAST Cooperative Research Centre. The service is led by metallurgist Brad Cowley whose staff use computer-aided design tools and software to optimise light metal component designs.

Recent projects by the Design and Prototyping Service include the upper suspension arms and X-frame roof structure for the aXcess Australia concept car and the die-cast magnesium seat for Henderson Industries in collaboration with ADC Forgecast, a local die casting company.

Cowley is positive about the potential of light metals to impact on Australia's urban environment, particularly air quality. And according to David Lamb, the focus on metals also makes good economic sense.

'Australia sits on enormous resources of aluminium and magnesium ores,' Lamb says. 'The Federal Government recognises the need to ensure that these resources are fully developed. That means supplying complex high-tech components such as car components to the world's auto industry.'

The budget for the entire hybrid vehicle project is tiny, compared with the hundreds of millions of dollars being invested in Japanese, European and US hybrid electric car development. But Lamb says Australian researchers have a history of delivering outstanding technology on small budgets.

'We represent good value,' he says. 'Our prices are right, we have the range of skills required to support a hybrid vehicle industry, and we have the technology. And it's a matter of national pride.

'With this project, we will end up with a prototype vehicle that will show the world what we can do. It's not an end goal in itself, but a means to foster the take-up of these technologies by our industry, so that we can hope to become self-sufficient, and not rely on imported technology.

'And if we can achieve that, there's a good chance we can get into the export business ourselves.'

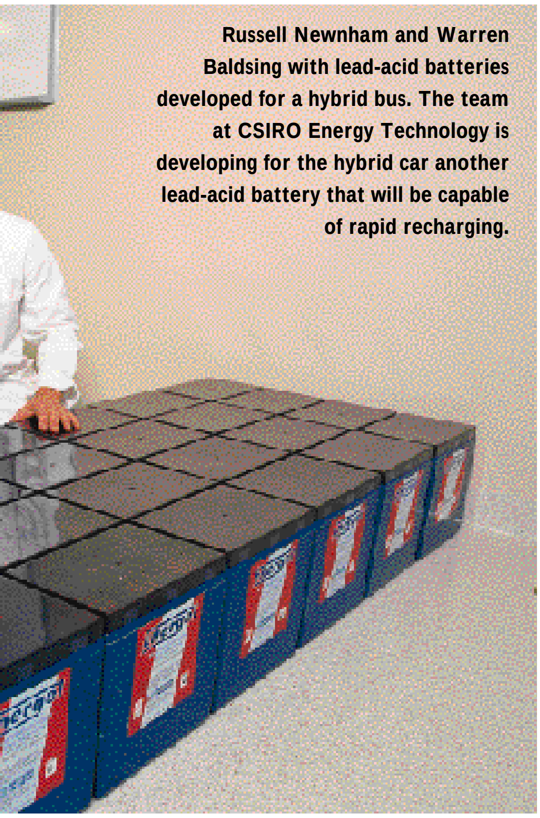
** The Novel Battery Technologies Group transferred from CSIRO Minerals to CSIRO Energy Technology in September, 1998.*

Green paint alliance

A NEW range of automotive paints destined to be cleaner, 'greener' and more durable than today's products is being developed by CSIRO Molecular Science and Du Pont Australia.

The new-generation tailored resins will be made using techniques that give precision control over the size and shape of polymers. As a result, fewer waste materials are generated and the need for solvents is significantly reduced. Other potential applications for the new polymers include adhesives and inks.

Du Pont is a major provider of automotive paints, a global industry worth an estimated US$5 billion a year. The paints are expected to become available early next decade.



Russell Newnham and Warren Baldsing with lead-acid batteries developed for a hybrid bus. The team at CSIRO Energy Technology is developing for the hybrid car another lead-acid battery that will be capable of rapid recharging.

A B S T R A C T

Australian scientists, backed by the automotive parts industry, are developing a hybrid internal combustion engine-electric vehicle. The imperative for the project is the undertaking by industrialised nations to reduce greenhouse gas emissions, particularly carbon dioxide and nitrous oxides. It will also promote Australia's technological and manufacturing skills on the world market. CSIRO is contributing expertise in rare-earth motors, lead-acid batteries and new-generation super-capacitors which provide bursts of power for rapid acceleration, plus electronic control systems, energy analysis, and design of low-mass metals and polymer composites to enable weight reduction.

Keywords: **hybrid internal combustion engine-electric vehicle; vehicle components; automotive research; capacitors; batteries; alloys; paints.**