Finding the energy to come clean

Fuel cells, cogeneration, hybrid systems, reversible chemical reactions . . . **Brad Collis** explores CSIRO's role in the future of energy generation.

Since the earliest humans learned to harvest fire for warmth and cooking, combustion has been our preferred form of energy. Combustible fuels have underpinned the progression of human society and industry for tens of thousands of years, but now this primordial fascination with fire must be suppressed to save our other life-giving resource: the air we breathe.

Changing atmospheric chemistry caused by an accumulation of combustion by-products such as carbon dioxide has been well chronicled as the greenhouse effect. Less appreciated, however, are the enormous changes in the way we create energy that will be required to slow down or reduce that accumulation.

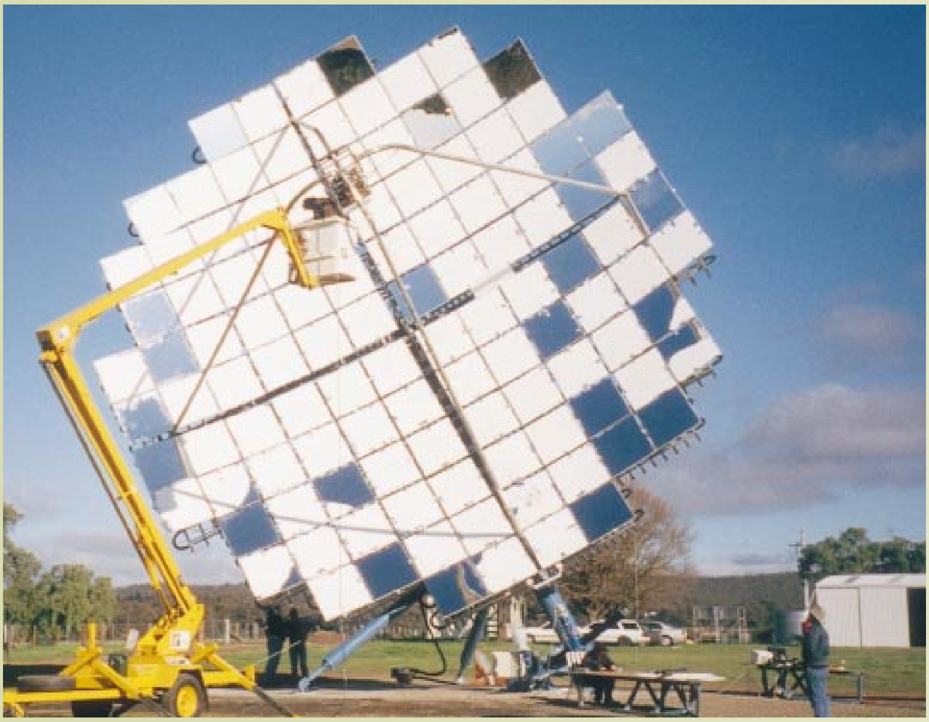
The coming decades are poised to be stamped in the annals of human history as 'the energy revolution'.

Comparatively recent discoveries of how to harness nuclear fission, and the sun, wind and tides, are just the beginning. Chemical energy, in the form of fuel-cells, for example, is likely to be a power-source for automobiles and for more distributed power supplies to our homes, offices and factories in just 20 to 30 years.

Some of the technologies will still use existing fossil fuels, but in processes vastly different to conventional combustion methods.

In Australia, all this will occur in a changing regulatory environment as the trend towards private, decentralised and competitive power utilities continues. In the not-too-distant future, individual suburbs and even individual buildings will have the capacity to supply all or part of their own energy needs through a combination of new energy-generation technologies. Consumers will have a greater choice in what fuel source provides their energy and more incentive to make their buildings much more energy efficient.

CSIRO Energy Technology is contributing to the large amount of research being done in these areas and is the only research organisation in Australia assessing the full range of sustainable energy technologies. Last year it released plans to build a sustainable energy research and demonstration centre for Australia (see story opposite).



Integrating fossil and renewable energy

Already under way is $7.5 million project to develop and demonstrate hybrid solar / fossil fuel electricity generation technology on the outskirts of Sydney.

The new systems will use conventional fuels more efficiently and cleanly and integrate them with renewable energy sources. This approach underscores the economic reality that for base-load electricity generation, fossil fuels can't just be abandoned.

The power generator facility will be comprised of a 12-metre diameter solar-thermal dish linked to a gas supply. It will provide a technical model for Australian power companies as they consider new ways to deliver electricity.

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Project leader, Jim Edwards from CSIRO Energy Technology, says the demonstration facility will produce about 20 kilowatts of electric power. High temperature solar energy will be used to chemically change any methane-containing gas, such as natural gas and coal-seam methane or methanol, to produce hydrogen and carbon dioxide.

Hydrogen produced from the solar conversion of methane will be trialled in fuel-cells and micro-scale gas turbines. These new technologies offer the prospect of power generation which, when based on fuel cells operated with gas turbines in combined cycle plants, can have efficiencies in excess of 60%, compared with 35–40% for coal-fired power stations.

In any commercial application of the concept, the carbon dioxide, which is in a concentrated form, can be disposed of in depleted oil and gas fields or deep unminable coal seams. The theory is that the carbon dioxide only needs to be kept away from the atmosphere for another 100 years, by which time fossil-fuels will have been phased out or be used in lower-emission technologies.

Edwards says the new technology will also open up opportunities for decentralising power generation away from large sites, such as the Latrobe Valley in Victoria and the Hunter Valley in New South Wales, to a network of small facilities powering townships, suburbs or even individual buildings.

Taking energy research to Newcastle

THE sustainable energy research and demonstration centre planned for Newcastle will demonstrate energy-efficient technology in its design and construction.

Optimum use will be made of the sun, with facades that bounce light into the building and innovative environmental controls. The outside will be clad in solar panels to generate electricity and a solar pond is being considered to heat water for space heating. Consideration will also be given to using geothermal heat pump technologies for air conditioning. The building materials will be chosen to minimise the amount of ‘embodied energy’ and greenhouse emissions involved in their manufacture.

The centre will employ more than 100 research staff and have an annual budget of about $11 million.

Existing and emerging technologies

To meet its international greenhouse gas commitments, Australia must stabilise carbon dioxide emissions to just 8% above 1990 levels by 2010. The Electricity Supply Association of Australia estimates that continuing to use existing power generation technology would result in a 43% increase in emissions from this source.

The Federal Government has mandated an additional 2% new renewables (perhaps as much as 9000 GWh) in its November 1997 greenhouse response package. This equates to approximately 4000 MW of new renewable plant, with a capital investment of at least $10 billion, but still not enough to stabilise greenhouse gas emissions from electricity generation. The required reduction can only come from increased use of gas and cogeneration technology.

Coal: Coal will continue to be a prime fuel for electricity, but the way it is used is going to change. Burning coal under high-temperature and high-pressure conditions is one way this conventional fuel can be transformed so that its energy conversion from fuel to electricity is increased and emissions are decreased.

In support of this, a new $2.5 million coal gasification research facility is being built at the CSIRO Pinjarra Hills site near Brisbane by the CRC for Black Coal Utilisation (in which CSIRO is a major partner).

The facility will be the centrepiece of a range of projects examining and specifying Australian coals for future export markets, and will develop a knowledge base for re-powering conventional plant and / or the building of new plant in Australia

This entrained flow gasifier follows a similar project undertaken in Victoria by HRL Ltd and the CRC for Utilisation of Low Rank Coals, to look at the possibilities of gasifying Victorian brown coals – a process known as Integrated Drying / Gasification Combined Cycle. This has the potential to reduce carbon dioxide emissions from power generation using Victorian brown coal.

Developments such as these mean that conventional fuels such as coals do not have to be abandoned. Nonetheless, coal will increasingly be supplemented by other energy sources.

Gas: One of these sources is natural gas. Modern industrial gas turbines are highly efficient, need little maintenance, and produce lower carbon dioxide emissions. Gas, which is easier to transport, also suits smaller decentralised electricity systems and its use can be extended as micro-scale turbine technology (below 50 kWh) develops.

One of the applications for gas is in urban-based cogeneration units: the generation of electricity and simultaneous collection of any heat by-product for uses such as hot water or air-conditioning. This technology is already used in the industrial sector and is expected to spread to smaller businesses and the residential / commercial market.

Like conventional industrial cogeneration, ‘minor cogeneration’ modules produce power plus heat in the form of high or low temperature hot water, steam or warm air, and even cooling by means of indirect heat absorption which can supply the individual house.

Direct use of gas could provide greenhouse savings of up to 470% over coal-fired electricity, so it is not surprising that there are major worldwide efforts to expand and accelerate direct use of gas in residential, commercial and industrial sectors. This includes air and space heaters, water heaters and boilers, cookers and ovens, air conditioning and refrigeration, and in a wide variety of industries – minerals, metals, glass, textiles, paper – for drying, smelting, coating and other applications.

Gas can also be used in fuel cells, an old technology approaching commercialisation as a new source of clean energy generation.

Harnessing wind energy relies on finding locations with strong, consistent winds and with the space to host many large wind turbines. Australia's largest and first grid-connected wind farm was established last year at Crookwell in New South Wales.

Four fuel-cell technologies – phosphoric acid, molten carbonate, ceramic (solid oxide) and polymer electrolyte exchange membrane – are under development for stationary and mobile energy generation. CSIRO is involved in a joint venture with Ceramic Fuel Cells Ltd (CFCL) to demonstrate and commercialise solid oxide fuel cells. Other participants are Energex, Western Power, Pacific Power, Electricity Corporation of New Zealand, ETSA Corporation, the Strategic Industry Research Foundation and BHP.

The ceramic (or solid oxide) fuel cell is an electrochemical device which consists of a thin sheet of zirconia-based electrolyte coated on both sides with special porous electrode materials. At high temperatures (800–1000°C) zirconia is an efficient oxygen ion conductor, so when a fuel gas such as hydrogen is passed over one surface (the fuel electrode) and an oxidant, usually air, is passed over the other (the air electrode), a flow of oxygen ions moves across the electrolyte to oxidise the fuel.

Electrons generated at the fuel electrode then migrate through any external load, such as a house's electrical appliances, to complete the circuit. Electrical power is generated for as long as fuel and air is fed to the cell, with a typical power output being two to three kilowatt hours per square metre.

This ability to convert a fuel's chemical energy directly into electricity provides the fuel cell with its high efficiency, offering about twice that achieved through conventional means. When using fuel cells for power generation the level of greenhouse gases (such as carbon dioxide) is halved, and the level of other pollutants is reduced to a fraction of those produced by fossil fuels combustion.

A fuel cell reaction also has collectable heat as a by-product. This can be used in cogeneration applications. Fuel cells can be connected to form 'stacks' that generate the voltage and current required. The output is direct current, which can be converted to alternating current.

CFCL will soon complete the conceptual design for a 25 kilowatt solid oxide fuel cell module.

Renewables

CSIRO research is focussing on three areas of new, renewable energy: biomass / waste wind and solar thermal.

Wind energy has the advantage of a readily available hardware and good economics. Overseas it is widely accepted, with Denmark sourcing 7% of its energy from wind. Today's mass-market wind turbine produces 600–750 kW and stands as high as a 20-storey building.

Fluid dynamics, topography, meteorology, demography, numerical modelling and statistics are all used to help identify prospective sites for wind turbines in Australia. CSIRO is a world leader in the measurement of wind and the modelling of potential wind energy yield in complex topography.

This work has led to the siting of Australia's largest and first grid-connected wind farm at Crookwell, NSW, in 1998. The farm's 5 MW output equates to an annual reduction in carbon dioxide emissions of 8000 tonnes, by replacing fossil power. A 10 MW wind farm is being designed for Blayney, NSW, and other sites are being assessed.

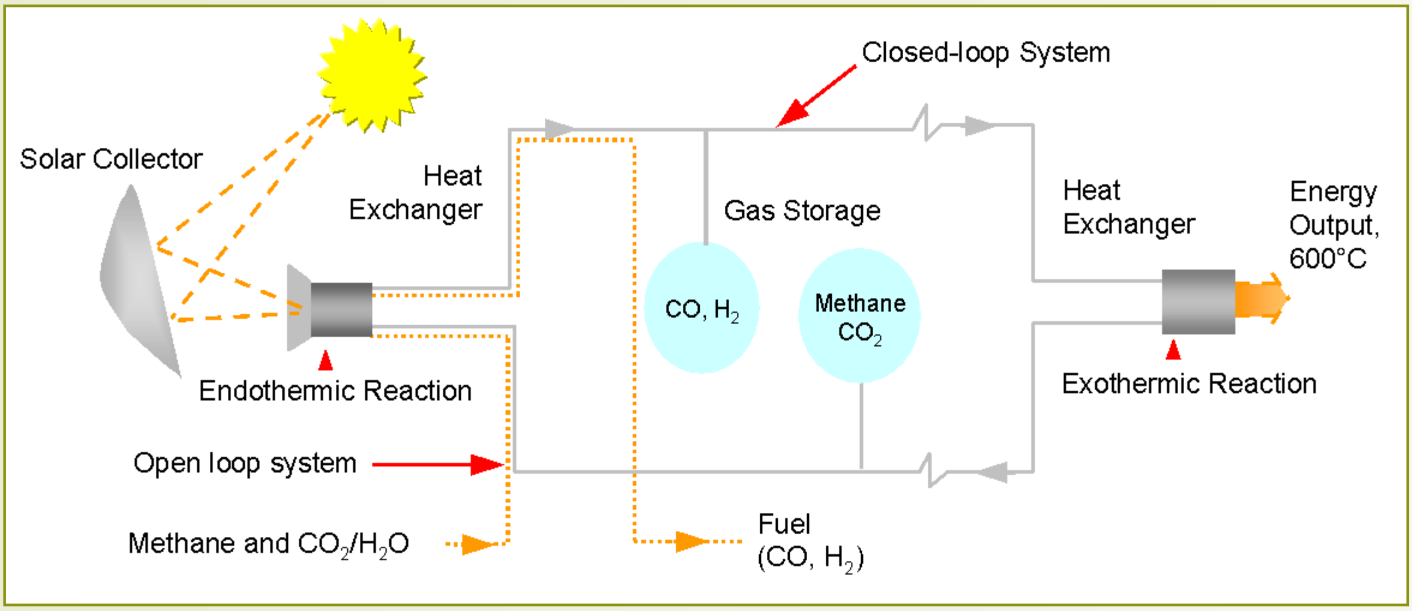
Biomass is the World's fourth largest energy resource. Its development in Australia would help to meet future targets for renewables-based electricity. CSIRO intends to apply its coal-based expertise to resolve technical issues relating to biomass energy production, including co-firing with coal. (See Bioenergy beckons, *Ecos* 98.)

Renewable energy from wind and solar sources, because of their low intensity and intermittent nature, are mainly used in niche applications such as remote Area Power Supply (RAPS) systems and for solar and heating systems.

Such electricity sources also rely heavily on energy storage technologies, which are dominated by lead acid batteries, which have also been the subject of recent technical advances.

The CSIRO batteries group has made major advances in extending the life of lead acid batteries, increasing their reliability and their storage capacity as well as speeding up the rate at which they can be recharged.

Working with an Australian company, Battery Energy South Pacific, the group has commercialised Australia's first gelled-electrolyte lead-acid battery (the SunGel). These batteries require no water or maintenance, and can be stacked and used in confined spaces and have applications in heavy-duty telecommunications and RAPS, and may be modified further for use in



Carbon dioxide/methane reforming has a number of advantages over other thermo-chemical storage systems: it can be used in open and closed loop systems and it can utilise gas derived from natural gas, from coal-bed methane or from landfill.

electric vehicles. Research is now focussed on finding new materials to make the separators in these batteries more robust.

The group's work to increase battery recharge rates is based on pulsing the charge into the battery, a method that also extends battery life. If successful, this technique could make the use of electric vehicles more acceptable.

The other form of storage being developed is supercapacitors, in which Australia is a world leader (see Batteries included, *Ecos* 97). Supercapacitors have the highest power-per-unit weight of any economically feasible energy storage device and can deliver high discharge currents with fast recharge rates.

Australian progress, through CSIRO and its commercial partner cap-XX Pty Ltd, has seen the commercial achievement of a 9 Watt hours per kilogram energy density. In an independent evaluation of supercapacitor technologies, the cap-XX supercapacitors were judged to have the highest power density of all those available.

('Energy density' refers to the amount of energy the supercapacitor can store, which is small compared to batteries. 'Power density' refers to the amount of energy it can deliver in a specific time.)

Supercapacitors will not replace batteries in vehicles, but could easily take over functions such as activating the starter motor and extending the battery's life. In combination, batteries and supercapacitors can provide unique performance by combining high power with high energy and have wide applications.

Another form of energy storage is reversible chemical reactions. Of the reactions being studied for solar-based energy storage systems, carbon dioxide / methane 'reforming' and its reverse reaction (carbon monoxide / hydrogen methanation) are one of the most favoured.

This process uses high temperature solar energy to supply the heat needed for the carbon dioxide / methane reforming. The reaction products (carbon monoxide and hydrogen) are stored or transported to a separate site and used for the reverse reaction (methanation) to release the stored solar energy. The methanation products are sent back to complete a closed loop cycle. Alternatively the product can be combusted (see diagram).

Australia is a world leader in the development of supercapacitors which are likely to be used in tandem with batteries to raise vehicle performance.

CSIRO worked with Pacific Power to improve catalyst performance and reactor design which can handle the large heat transfer requirements characteristic of energy storage systems. The expertise gained in developing this technology has been incorporated and further refined in the CSIRO's new hybrid energy project

Such technical alternatives to conventional power generation come at a price. The power cost of the solar station is 3.5 times more than that for the conventional coal-fired power station. However, on-going research and development should eventually reduce these costs.

Abstract: New energy-generation technologies are needed to reduce the accumulation of combustion by-products in the atmosphere. CSIRO Energy Technology is contributing to their development with a demonstration hybrid solar/fossil fuel facility and plans to build a sustainable energy centre at Newcastle. Coal will continue to be a prime fuel for electricity, but the efficiency of its conversion will be increased. Gas is likely to be used more in cogeneration and in fuel cells which convert chemical energy directly into electricity. CSIRO is also undertaking research in wind, biomass/waste and solar thermal energy. Advances are being made in energy storage systems such as lead acid batteries, supercapacitors and reversible chemical reactions.

Keywords: power generation; renewable energy; solar energy; wind energy; fossil fuels; coal gasification; gas; fuel cells; batteries; energy storage; supercapacitors.