INDUSTRIAL RESEARCH LIMITED

SOLID ENERGY
Coals of New Zealand

CRL Energy Ltd

The New Zealand solution

A NEW COAL TECHNOLOGY PACKAGE FOR THE HYDROGEN ENERGY ECONOMY

February 2004

CRL Energy Ltd and Industrial Research Ltd

in partnerhip with Solid Energy New Zealand Ltd and the

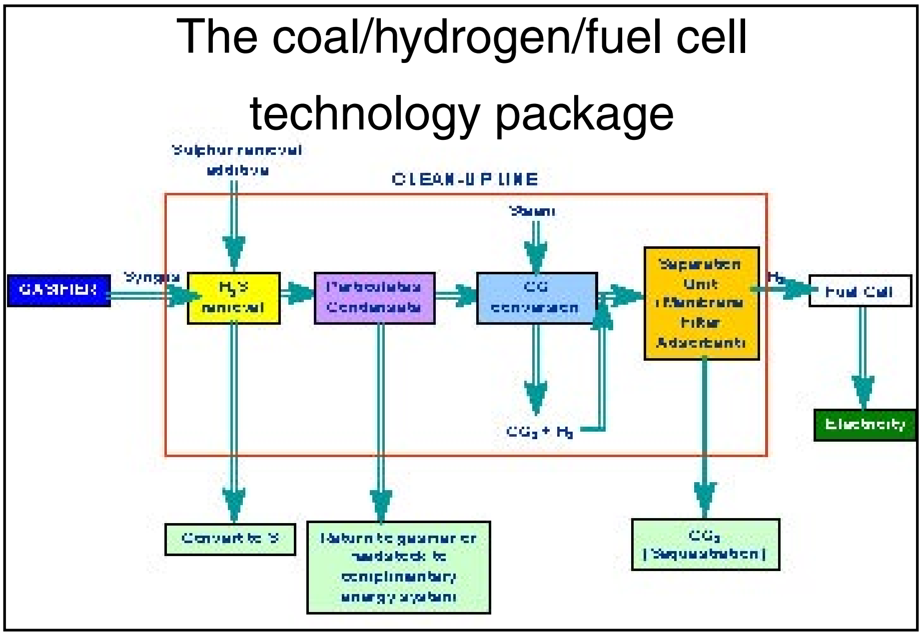
Coal Association of New Zealand

COAL ASSOCIATION OF NEW ZEALAND INC. AND CRL ENERGY LTD

New Zealand's hydrogen-energy future

The promise of hydrogen

The promise of a hydrogen-based energy economy is clean and secure energy for all, forever. At a time of raised awareness of local and global impacts of pollution, on-going instability in the Middle East and the uncertainty of supply, this is an extremely attractive proposition. Combining this with the significant advances that are being made in the high efficiency fuel cell technologies used to convert hydrogen to energy and the hydrogen energy option becomes not only attractive but achievable.



New Zealand's Contribution

Billions of dollars are being invested into hydrogen energy research around the world as the transition to hydrogen energy begins. Much of this work is focused on developing and demonstrating large scale technologies. There are opportunities for New Zealand to benefit from being a technology shaper rather than a taker - particularly in the area of small scale hydrogen technologies for distributed energy generation.

Hydrogen can be produced from water (using electricity) and from coal or natural gas. Coal-based production technology currently looks most promising for early delivery of a hydrogen economy. With over 10 billion tonnes of coal reserves, almost all ideal for hydrogen production, New Zealand is positioned to be leaders in the development of the hydrogen energy economy.

Recognising this, in June 2002, the New Zealand government through the Foundation for Research, Science and Technology (FRST) announced a $6 million investment "Hydrogen Energy for the Future of New Zealand" as a first step in New Zealand's transition towards a hydrogen energy economy.

The programme is a partnership between major research providers CRL Energy - with expertise in coal gasification and gas clean-up - and Industrial Research with expertise in gas clean-up, fuel cells and power conditioning for small scale distributed electricity generation. Unitec and the Centre for Advanced Process Engineering are sub-contractors to the programme. Solid Energy is providing additional support. The programme is overseen by a Governance Panel comprised of senior industrial representatives from Solid Energy, BP New Zealand and Meridian Energy and including one representative of FRST.

In addition to the government, Solid Energy and the Coal Association have initiated and invested in related areas of advanced technological and environmental issues. These include the development of a Hydrogen Roadmap for the Coal Industry and technologies and options for sequestration of the CO_2 by-product of hydrogen production from coal.

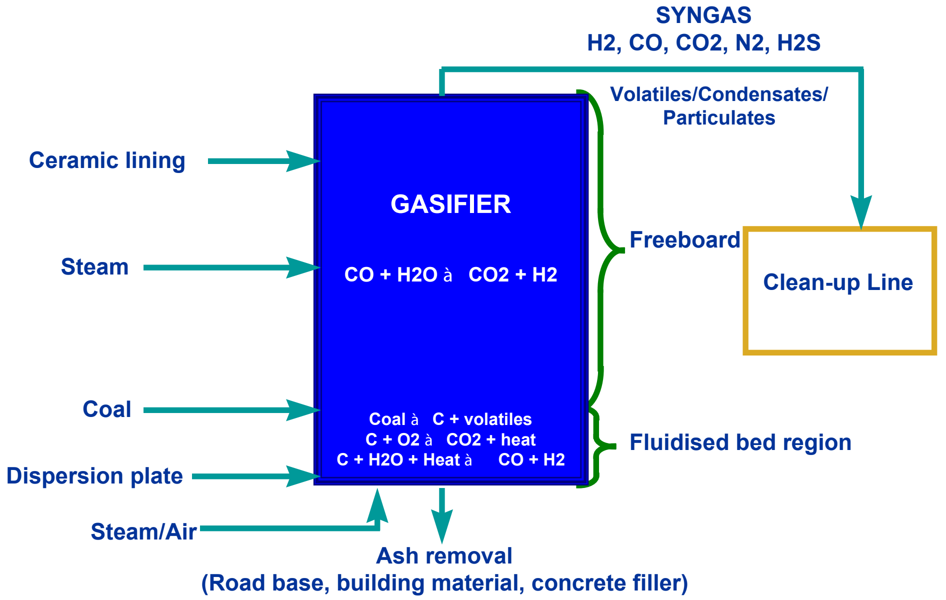
New Zealand has sufficient coal reserves to last for many centuries and they are well suited to play a major role in our transition to a hydrogen economy. Much of the coal reserve is very reactive and ideally suited towards a new clean coal technology called fluidised bed gasification. One major aim of the "Hydrogen Energy for the Future of New Zealand" Progamme is to take full advantage of this property and prove the concept of a totally new hydrogen-based energy system that leads from coal via gasification to hydrogen and from hydrogen via a fuel cell to electricity.

The immediate target of the "Hydrogen Energy for the Future of New Zealand" programme is to prove this new package at the 50 kW scale – sufficient to meet the needs of 10 to 20 houses or of a small sized commercial operation.

The coal gasifier – first step in making hydrogen from coal

A coal gasifier is a container into which is fed coal, air (or oxygen) and steam. Inside, three critical events take place. Firstly, volatiles are released from the coal to produce a char. Secondly some of the char and volatiles are combusted to generate heat and thirdly the

Fluidised bed gasifier component of the coal to hydrogen package



remaining char reacts with steam to produce hydrogen and carbon monoxide. The last of these is the coal gasification reaction. It requires heat to drive it and this is provided by the combustion step. It can also be catalysed by the presence of calcium and it so happens that many of our New Zealand coals contain calcium in the correct form to perform this catalyst role – hence their high reactivity.

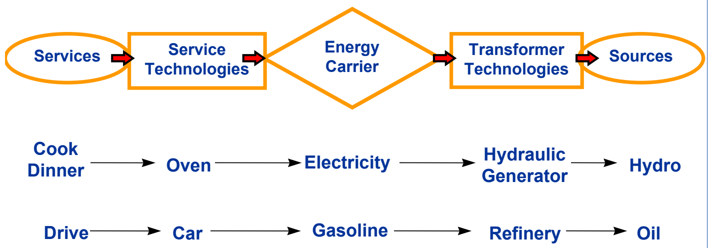
Syngas, a mixture of hydrogen and carbon monoxide, emerges from the gasifier along with carbon dioxide and smaller amounts of other products. A clean up line is used to remove any condensates, particulates and sulphide gases from the syngas stream before it is passed to a filter or membrane for hydrogen separation. The hydrogen then passes to an alkaline fuel cell for electricity production. This is the most demanding of all fuel cells (indeed the most demanding of all the known hydrogen conversion technologies) in terms of hydrogen purity demands, but one well suited to distributed electricity generation applications.

Understanding the hydrogen-based energy system

To appreciate why a hydrogen-based energy system offers clean and secure energy requires an understanding of energy systems. All are devised to do the same thing - use the energy sources provided by nature to deliver services required by humanity. All require a technology to convert nature's energy resource into an energy carrier and a technology to enable the consumer to utilise that energy once delivered.

Here are two current examples.

Current Energy System

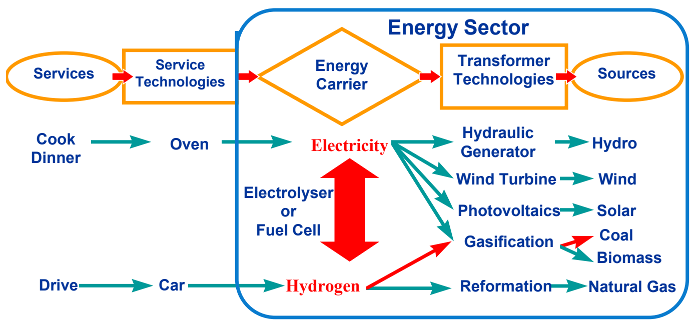


In the top line, the nourishment required by the consumer arrives at the end of a system beginning with a hydro lake, via a generator to produce electricity which carries the energy to the consumer's home where it runs an oven. In the line below, the requirement to rapidly get from point A to point B is met by a system beginning with a supply of oil, via a refinery to produce petrol which carries the energy to the consumer's car.

The same services under a hydrogen energy system look like this.

In the energy system with H_2, shown on the previous

Energy system with H_2



The transition to hydrogen energy systems

page, the top line remains largely intact. The big change occurs in the bottom line where petrol is replaced as an energy carrier by hydrogen. This leads to a situation where for the first time the two major energy carriers in the system, electricity and hydrogen, are interconvertible. In essence, electricity passing through water picks up a proton to produce hydrogen and hydrogen passing through a fuel cell releases the electron to produce electricity. The overall result is that a level of opportunity, flexibility and integration, previously unattainable, is now introduced into the energy system.

The prospect of "clean and secure energy for all forever" now emerges. Clean, as water is the only significant by-product when hydrogen is used to produce energy, and secure, as every nation is sufficiently fortunate to have an abundance of at least one of the listed energy sources.

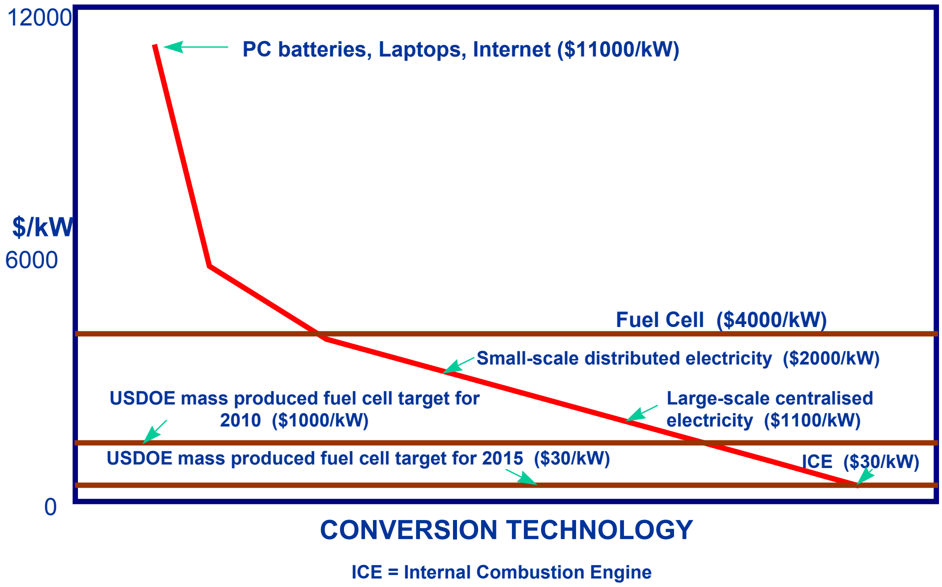
The transition to hydrogen-based energy systems

The transition to hydrogen energy is already happening and rapidly gaining momentum globally. Some recent events include:

- August 2002 - General Motors unveil the world's first purpose built hydrogen powered concept car – the Hy-Wire – and announce their intention to begin mass production by 2010.
- November 2002 - The world's first hydrogen energy station with co-production of hydrogen for vehicles and power production opens in Las Vegas.
- Late 2002 to early 2003 – most of the worlds largest automobile manufacturers have begun commercial production of fuel cell vehicles, typically in batches of 10 to 100 vehicles.
- October 2003 - 69 hydrogen refuelling stations in operation in a diverse range of countries including the United States, United Kingdom, Japan, Iceland, Spain, Portugal, India, Australia, Germany, Holland, Luxembourg and Sweden. Major cities in many of these countries are using hydrogen demonstration vehicles in their public transport fleet.
- November 2003 - the International Partnership for Hydrogen Energy, for international cooperation in the production, delivery, storage and utilisation of hydrogen is formalised in Washington D.C. Signatories to the Partnership include Australia, Brazil, Canada, China, France, Germany, Iceland, India, Italy, Japan, Norway, Republic of Korea, Russia, United Kingdom, the United States and the European Commission.

The initial widespread use of hydrogen fuel cells is occurring as a replacement power source for PCs, military power packs and other electronic devices. The next application may be in small-scale distributed electricity situations. Transport applications will eventually be the most high profile application of hydrogen energy but the widespread uptake of fuel cell vehicles is not likely to occur until the middle of the next decade.

The graph on this page shows a likely sequence of events based on existing comparative costs of fuel cells with those of batteries, small and larger scale electricity generation systems and internal combustion engines.



Issues facing a hydrogen energy economy

The transition to hydrogen energy represents a fundamental change to society as far reaching as the introduction of the automobile, the aeroplane, the internet and the cell phone. As with those new technologies there are some considerable barriers and all of us ultimately have a critical role to play in overcoming these.

The big challenges of making the transition to hydrogen are well defined and long debated. All are increasingly being targeted for major government and industry investment globally.

The big seven challenges range across the spectrum of the hydrogen energy system. In reality all are interlinked but in order to understand them more clearly it is worth considering each separately. They are:

Production

Hydrogen, like electricity or petroleum is an energy carrier – not an energy source. Although the most abundant element in the universe, it cannot be mined or harnessed on earth in the way solar, wind or coal can. It must be produced from these sources. Each country will have its own unique blend of energy sources from which to best meet its hydrogen production needs. There are existing commercial processes for production such as coal gasification, natural gas reformation and electrolysis using electricity generated from renewable energy sources.

Improvements in hydrogen production efficiency and costs are required for all these methods and promising new methods, including biological production, need further development.

Production from fossil fuels such as coal requires a particular emphasis on gas clean-up and improving costs of separation, capture and sequestration of the greenhouse gas by-product CO_2 .

Delivery

Once produced, an extensive network is required to deliver the hydrogen to where it is to be used. The delivery system must be reliable, safe, convenient and cost effective. Many developed countries already have mature hydrogen based industries and, to some extent, a mini-hydrogen energy delivery system based on use of pipelines, or by road using cylinders, tube trailers or cryogenic tankers. In a hydrogen energy future all are likely to play a role with pipelines to deliver hydrogen to high demand areas and trucks to deliver to more remote sites. The alternative of moving the energy source and producing the hydrogen on site (distributed generation) will also be, to varying degrees, part of a nation's hydrogen delivery system.

It is often stated that hydrogen leakage is a major problem for the delivery infrastructure. This is only the case for liquid hydrogen where evaporative losses may occur. For pipelines, cylinders and tube trailers, leakage is minimal.

Each country needs to identify and develop the delivery system best suited to its own particular circumstances and requirements.

Storage

For a vehicle to achieve a range of 250 to 300 km requires about 3 kg of on-board hydrogen. Left untouched, this amount of hydrogen would occupy a very large and impracticable volume. One option is to compress it and store it in on board in high pressure, high strength storage tanks. This technology is commercially available and is used in fuel cell concept vehicles. Compression is an energy demanding process and an alternative is to use high density storage in reversible metal hydrides, carbon nanotubes and chemical hydrides such as sodium borohydride. Many of these alternatives have energy storage densities similar to those of liquid fuels but it is essential that they reliably release the hydrogen when required under well defined and readily attainable temperatures and pressures. These technologies are still in the developmental stage.

Conversion technologies

Hydrogen can be used in engines and turbines as well as fuel cells. Fuel cells have higher energy generating efficiencies than engines and turbines but to date no single fuel cell technology is able to meet all the performance, robustness and cost parameters demanded by consumers. Engines and turbines are much closer to doing so but more information on flame characteristics of hydrogen combustion is needed – particularly in the case of turbine design.

Consumer applications

There must be a robust value proposition to convince the consumer to choose hydrogen for power, heat and transport needs. When it comes down to it few consumers will willingly pay a cent more for the privelege of clean and secure energy for all forever, desirable as it may be in the grand scheme.

The most high profile application is in the transport sector where vehicles will have to be as affordable as the existing conventional petroleum combustion engine option, have comparable or better range, startup reliability, ruggedness, acceleration and speed. One of the biggest efforts of the automobile manufacturers is to identify the extras offered by a hydrogen-powered car. For example the General Motors Hy-Wire concept car builds on the realisation that since an engine is no longer needed, buying a car becomes akin to buying a glorified skateboard to which the body of choice may be attached. This could be a sports car, station wagon or sedan, or the consumer may own all three at once.

No person or organisation has, to our knowledge, yet grasped the full implications of hydrogen and identified clearly all the societal changes it will allow. The situation was recently described most succinctly by comparison with the "high jump industry." Everyone knows the aim of the high jump is to clear the bar and land safely. For decades, if not centuries, there was a certain way of performing the high jump based on this established wisdom. In 1930 someone thought to introduce large blue bags into the landing area to make it safer but not until 1968 was it realised that the blue bags had fundamentally changed the industry so that it now consisted solely of clearing the bar by whatever means. The Fosbury flop was introduced and in short order the world record height increased by approximately 30 cms. Hydrogen is a "blue bag" for society.

Education

Informing consumers, industry leaders and public policy makers about hydrogen energy is a critical issue. It will be achieved through a wide range of educational and training materials, science courses at all levels (primary through tertiary), technology demonstrations and public outreach programmes.

Codes of Practice

The widespread use of hydrogen will require uniform codes and standards for design, manufacture and operation of all aspects of a hydrogen energy system. Ultimately these codes must be transferable between nations and accepted by international bodies.

As with any fuel, safe handling depends on knowledge of its particular physical, chemical and thermal properties and identification of safe ways to accommodate those properties. Hydrogen, handled with knowledge is a safe fuel. Industries worldwide have used huge volumes of hydrogen safely and routinely by following standard codes and practices that have been established in the past 50 years. These practices can be emulated in non-industrial uses of hydrogen to attain the same levels of safety and routine handling.

Future developments of the Hydrogen Energy Programme

The hydrogen based energy system developed by the FRST "Hydrogen Energy for the Future of New Zealand" programme is well suited for building the expertise and knowledge platform to launch New Zealand into a hydrogen energy economy. It is also a component of the multi-component, highly flexible zero emissions coal fired plant of the 21st Century. These plants are likely to become a significant part of the worldwide energy landscape during the transition towards the hydrogen energy economy.

This plant will begin with coal gasification. Its flexibility is based on the fact that the syngas product may, with minimal clean-up be used in engines to produce electricity. With a little more clean-up it may be used in a combined cycle gas turbine/steam turbine plant. Further clean-up makes it suited for use in solid oxide and molten carbonate fuel cells – the ones best suited for larger scale electricity production – while rigorous clean-up yields high purity hydrogen for use in the alkaline and proton exchange membrane fuel cells suited for smaller scale distributed generation and transport applications.

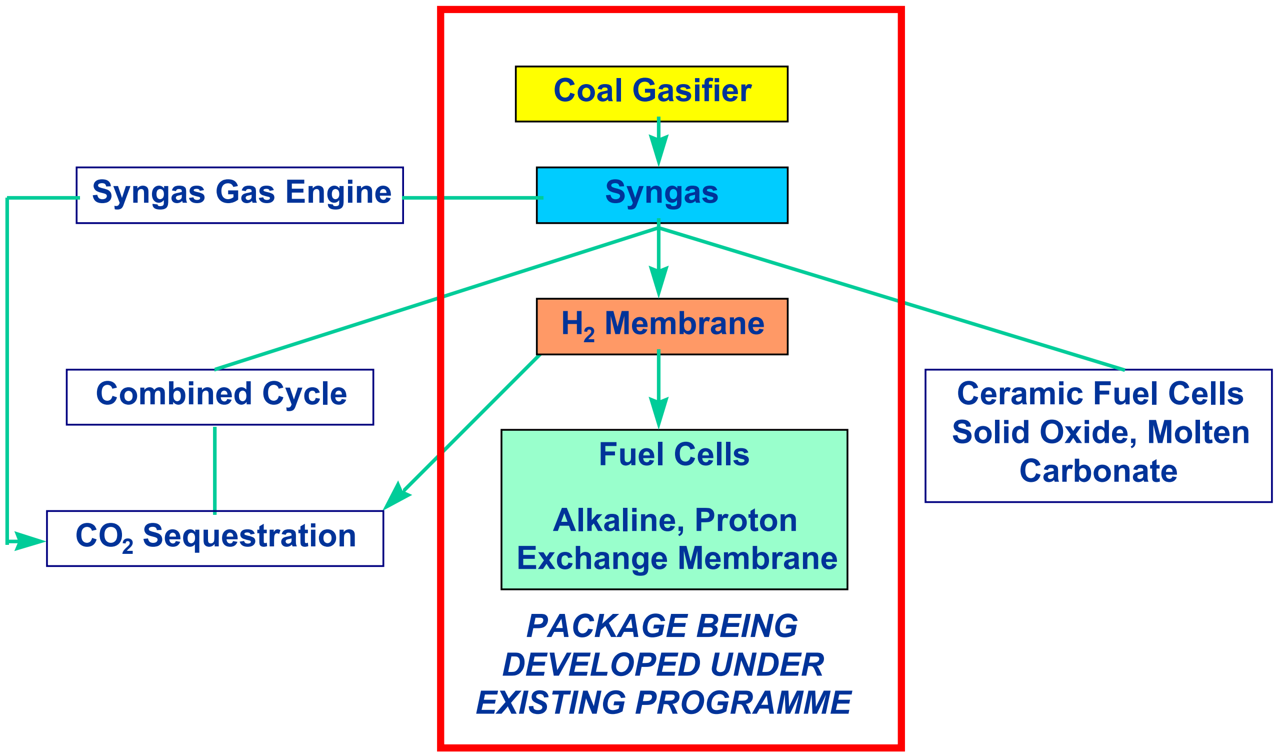
The coal fired plant of the 21st Century will contain all these components along with decarbonisation achieved by CO_2 separation, capture and geological sequestration.

A natural extension of the hydrogen based energy system being developed by the existing FRST programme is to incorporate it into a demonstration of a larger scale 21st Century coal fired energy plant containing all the above technologies and capabilities. This is an ambitious project but one to which Solid Energy and CRL Energy are committed to achieving for New Zealand.

Photo credits

Front Page: Hydrogen-powered bus, Hamburg, and hydrogen station, Iceland , courtesy of Norsk Hydro Electrolysers, Norway. CRL's Coal gasifier, Louise Thomas, Wordwise Science Communication. Strongman Opencast Mine in Greymouth, Solid Energy. IRL's Fuel Cell, IRL. Hydrogen-powered car, Honda Cars, US.

PROJECT 450
zero emissions coal-fired power complex proof of concept



About CRL Energy Ltd

CRL Energy Ltd is an energy and environmental consulting company, with a strong research and testing base and a specialist knowledge in all aspects of the energy chain. As well as specialist knowledge in new energy technologies such as hydrogen and biomass conversion, we have a strong history in all aspects of fossil fuel energy, particularly coal research, offering research, consultancy and testing in the areas of exploration and mining, fuel quality and use, and environmental monitoring.

CRL Energy is a Telarc Registered Supplier to ISO9001. Our chemical laboratories and energy test centres provide a solid practical basis for all our work. We have on-going research contracts with the Foundation for Research, Science and Technology, Technology New Zealand, Energy Federation of New Zealand, World Energy Council, and the New Zealand coal industry.

Our main laboratories, test facilities and library are on the Science Campus at Gracefield, Lower Hutt. We also have:

- A geology and hydrology team based at our Christchurch office on the University of Canterbury Ilam campus.
- An environmental team in Hamilton based on the Ruakura Science Campus.
- A coal and water testing laboratory, and mine geology service in Greymouth.

Analysis & Testing

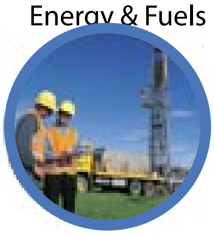
CRL Energy offers a comprehensive range of solid fuel analytical tests, with IANZ accreditation for the most important tests. We offer both chemical and petrographic analysis.

CRL Energy's capability includes fuels, such as gas, wood and biomass. Our Greymouth and Gracefield laboratories offer IANZ accredited chemical and microbiological water sampling and testing services.

Geological, Geotechnical Engineering & Hydrogeological Services

The mix of geo-consulting skills available from CRL Energy can be applied to any type of land development, from small subdivisions to large-scale mining. The geological team at CRL Energy's Christchurch Office gives clients an integrated service for the interpretation of geological data, from the exploration stage through to mining and production. Our petrographic and palynological expertise and our seam modelling techniques offer clients a premium service for exploration and characterisation of coal deposits.

Energy & Fuels



CRL Energy's combustion test centre offers testing programmes tailored to meet the needs of individual clients. Our 50kW combustion test rig can test and evaluate fuel performance under controlled conditions. Our gasification bench-scale test rig is ideally suited to measuring char reactivities, with the capability of rapid and accurate measurement of gas mixtures.

Environmental Monitoring

CRL Energy measures particulate emissions from wet or dry gas streams and offers a size distribution analysis. Size fractions as low as 2.5 microns can be quantified. We offer at-source pollutant gas emissions measurement with our portable gas analyser. Our dust deposition monitoring service will measure ambient dust present at work sites and near stockpiles. We help companies to reduce carbon dioxide emissions by advising them on boiler efficiencies.

Climate Change

We have an excellent reputation in providing a wide range of climate change related services such as research, consultancy and education.

CRL Energy Ltd

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