Design, Construction and Commissioning of a Coal to Fuel Cell Grade Hydrogen Technology Package

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Abstract

One of the most important questions when considering the development of a hydrogen infrastructure is "where will the hydrogen come from?" It is up to each country to develop the options best suited to its own particular mix of energy sources. New Zealand has sufficient recoverable coal reserves to last for centuries and dwindling gas supplies. It relies heavily on hydro-electricity but this option is struggling to keep up with growing demand.

Recognising the need for a wider range of supply options, the New Zealand government has invested in a six-year research project "Hydrogen Energy for the Future of New Zealand" to create the technological platform required to allow New Zealand to realise the benefits of moving to a hydrogen based energy economy and to demonstrate a small scale "coal to high purity hydrogen to electricity" distributed generation package at the 50 kW scale.

This new energy technology package is now built and commissioning work has begun. This paper describes some of the features of the gasifier and syn-gas clean-up components of the technology package, some of the difficulties faced and means of overcoming them.

The Hydrogen Economy in New Zealand

New Zealand, in common with many countries, is faced with the issues of increased energy demand and the long-term environmentally sustainable production of energy to meet that demand. It has dwindling gas reserves, well utilized hydro and geothermal resources, a significant and growing quantity of biomass (crops and process residues) and is beginning to develop its wind energy resource. It also has in excess of 8.6 billion tonnes of known economically mineable coal reserves – sufficient to meet projected energy demands for many centuries into the future.

New Zealand's electricity generation sector is in the position of currently having very little excess generation capacity and being heavily reliant on renewable generation resources (mainly hydro). Thus, in the last few years, the threat of power shortages during the winter as a result of so called "dry years", (where there is a shortage of hydro generation reserves), has become a regular concern.

As a consequence of the challenges in electricity generation outlined in the previous paragraphs, the energy sector in New Zealand has been undergoing rapid changes over the past few years and the current year was no exception. One of the biggest events to occur in the past year has been the cancellation of a major hydro based electricity generation scheme, Project Aqua. Project Aqua involved damming the lower reaches of one of New Zealand's largest rivers, the Waitaki, to provide 524 MW of electricity generation capacity and irrigation water for the surrounding farmland. The additional 524 MW of generating capacity was seen by many as the short term answer to New Zealand's increasing electricity demand. Project Aqua was cancelled largely because of problems and escalating costs associated with to ongoing resource consent process. This decision has effectively signalled that there is unlikely to be any further large scale hydro developments in New Zealand in the near future and the focus for new generation capacity has moved to other renewable energy sources and, increasingly, coal, our largest known energy resource.

The increased pressure for a secure and reliable electricity supply has served to further increase coal's profile, and acceptance by the public, as a potential source of future electrical generation capacity. The public, energy sector and government alike, while becoming more accepting of the need for coal based electricity generation in New Zealand, are looking for coal based technologies that will allow New Zealand to meet its electricity demand whilst using coal in the most efficient and environmentally acceptable manner. As a result, there is increasing interest in coal gasification and the possibilities that this technology unlocks for large scale hydrogen use in New Zealand.

New Zealand is paying increasing attention to the potential benefits of moving toward a hydrogen based energy economy. The recent rapid advances in hydrogen utilization technologies, most notably in fuel cells but also in microturbines and internal combustion engines, coupled with the need for producing increased amounts of clean energy, represent a powerful combination of drivers for a hydrogen energy economy. There is the added factor of energy security. New Zealand spends between $2 billion and $4.5 billion dollars per annum on imported hydrocarbons and the prospects of reducing or eliminating that amount, and the foreign exchange uncertainties associated with it, by using hydrogen produced from indigenous sources represents a further potential benefit of moving to a hydrogen energy economy.

Consideration of the above and other factors have lead to the initiation of government investment into a research programme "Hydrogen Energy for the Future of New Zealand" in 2002. The programme goal is to develop the technology platform, knowledge and expertise necessary to underpin the introduction of a hydrogen energy infrastructure into New Zealand.

A major part of the programme is to demonstrate a coal to hydrogen to fuel cell to electricity package at the small scales (<1 MW) which are likely to be typical of the distributed generation systems that could arise in New Zealand. The specific goal is to demonstrate the entire package at the 50 kW scale firstly in the CRL Energy laboratories and later at a remote site – possibly as part of a distributed generation package.

CRL Energy is a co-leader of this programme with the specific role of producing high purity hydrogen from New Zealand coal. Although the aim is to clean-up the syngas to the point where it is sufficiently pure to meet the requirements of alkaline and PEM fuel cells it is likely that other conversion technologies, less demanding in terms of hydrogen purity, will be connected to the system at appropriate stages of the gas clean-up process.

One of the main factors underpinning the decision to aim at proof of concept for small scale distributed electricity generation is that generating the hydrogen at the point where it is to be utilized can considerably reduce the difficulties associated with its storage and distribution and thereby keep infrastructure related costs/issues as low as possible.

The Small Scale Coal to High Purity Hydrogen Conversion Package

A major feature of any chemical processing plant (and our pilot plant is no exception) is the system by which the process is controlled. When selecting an appropriate control system, the following features were identified as being of major importance.

- Reliability of operation
- Ease of programming and use
- Flexibility of the system
- Scalability
- Cost

With these features in mind a number of possible types of systems were investigated, evaluated and discarded before the final solution was selected. The system that we have purchased and are in the process of configuring is DeltaV from Emerson Process Technology. DeltaV offers the reliability of a PLC based system with the convenience and ease of use of PC based graphical programming. In DeltaV all the commonly used control block structures already exist. The operator therefore only has to assemble the existing control blocks into the required configuration and programme the specific details and variables appropriate to each block. For example existing PID control blocks can be used to control motors, valves etc. The appropriate inputs and outputs to the PID control block are wired graphically and the control variables set. An additional feature of DeltaV is a programme that can be used to self-tune the control block for the desired operation. An attractive feature for an experimental/pilot system is the ability to change operating parameters and make small changes to the structure of the control loops in real-time. This can be easily achieved within the DeltaV control environment. A long term aim of the research programme at CRL Energy is to take the 50kW H_2 package that is being developed in this research programme and scale it up for demonstration in a distributed generation environment. The DeltaV platform allows expansion of the number of I/O’s up to a possible 30,000 allowing huge scope for extending the current plant monitoring or the application of the current control system to a much larger and more complex plant. Licensing of the control system is based on the number of I/O’s used. This has allowed us to develop quite an advanced control system for what is, in industry terms, a relatively small application.

Another important feature of the pilot plant is the method used to start the gasification process.

Gasification plants typically have long start-up times due to the thermal mass of ceramics and other materials in their construction. This is undesirable for our pilot plant as there will be numerous start-ups and shutdowns while we commission, optimise and experiment with different syngas cleanup technologies. To overcome this potential difficulty electrical heating elements have been fitted to the outside of the ceramic casting that forms the fluidised bed of the gasifier. This system of heating the bed to start temperature has been commissioned and appears to work well. It offers us two main advantages.

1. 1. The bed can be maintained at near start-up temperature between experimental runs reducing the start-up times.
2. 2. The ceramic is heated from the outside eliminating potentially damaging thermal stresses that can result from heating the ceramic internally.

A major issue for the design and operation of a small scale coal to hydrogen technology package has been the application of conventional large scale cold gas sulphur scrubbing technologies on such a small scale and in a cost effective manner. Initially is was envisaged that we would design and use a small scale conventional packed column absorption tower that utilises MDEA as an absorbing solvent for removal of H_2S (which is produced during the gasification of coal). After in depth engineering and cost analysis this option proved to be unsatisfactory. Instead it has been decided to use a proprietary sulphur scavenger to eliminate H_2S from the syngas stream. Although not tested as yet, it is hoped that this method will provide a practical and economic solution.

Particulates will be removed in two stages; initially in a high efficiency cyclone and then in an ejector venturi scrubber in which the syngas is quenched and any remaining particulates, tars and condensables are removed.

Although it is expected that the extent of conversion of CO to CO_2 will be high due to the catalytic effect of the calcium in the coal on both the gasification and water gas shift reactions, use of a water gas shift reactor is planned to maximise the yield of H_2 from the syngas stream.

The last and arguably the most important step in the syngas cleanup process is the separation of hydrogen from the other remaining syngas constituents. Two methods are being considered at present; the proven method of Pressure Swing Adsorption (PSA) and the more experimental palladium membrane techniques. It is anticipated that while syngas purification via a palladium membrane should be able to be demonstrated at low syngas flow rates, the current cost and reliability issues surrounding this method would make it unsuitable for processing the entire syngas flow. A small palladium membrane has been purchased and is currently being configured for use in purifying a small slipstream of syngas early in the project. Meanwhile a suitable PSA unit is currently being sized to match the requirements of the gasification system.

The high purity hydrogen produced by this process is to be used in an alkaline fuel cell, provided by our research co-leaders Industrial Research Limited, to produce electrical energy for export into the electricity grid. Alkaline fuel cells are low temperature devices with a requirement for hydrogen at ambient temperatures. The syngas cleanup line is therefore able to consist of more established cold gas cleanup technologies rather than the more experimental hot gas cleanup technologies that are currently being investigated for use in IGCC plants.

While the pilot plant being developed is going to meet the research aims and objectives of this current programme, it is hoped that this pilot plant will be used as a test bed by developers of complimentary technologies. At this time we are in negotiation with several organisations regarding the use of this facility. We would welcome the opportunity to engage with other interested parties.

Conclusions

There is great potential for coal to play an important role in the transition to a hydrogen energy economy in New Zealand. A significant part of the New Zealand government's investment into the "Hydrogen Energy for the Future of New Zealand" programme is focused on proving the "coal to high grade hydrogen to electricity package". A large proportion of the New Zealand coal resource is well suited for fluidised bed gasification.

It is likely that hydrogen will initially be used as part of a distributed energy option. The immediate goal of the Hydrogen Energy programme is to demonstrate the complete package at the 50 kW scale but it is envisaged that the facility being developed to achieve that aim will become a focus for other hydrogen research initiatives and will find use as a test-bed for other hydrogen conversion technologies and gas clean-up options. The New Zealand government is developing policies around the concept of New Zealand as an international test-bed for new and emerging technologies and hydrogen based distributed generation systems is recognized as being well aligned with this concept.

Acknowledgments

We are grateful to the New Zealand government through the Foundation for Research, Science and Technology, Solid Energy, Coals of New Zealand, Ltd and the Coal Association of New Zealand for their investment in this research.

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