Commissioning of a Coal to Fuel Cell Grade Hydrogen Technology Package

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Abstract

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.

The new energy technology package for converting New Zealand low rank coals to high purity hydrogen suitable for use in fuel cells is built and commissioning work is well advanced. 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 paper also considers the likely role of coal based hydrogen production technologies in the development of a hydrogen energy economy in New Zealand. Given that New Zealand has sufficient recoverable coal reserves to last for centuries, dwindling gas supplies and insufficient economically viable renewable resources to meet likely future demand, it is recognised that there will be a transitional period of several decades during which hydrogen production from coal will play a major role.

Three applications of coal to hydrogen technology are considered – meeting the needs of small remote communities using a technology package similar to that being developed by CRL Energy, meeting the demands of a large industrial complex, and centralised production of the bulk of the hydrogen required to meet the needs of the future transport fleet.

Developing the coal to hydrogen technology package:

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 known 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. 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.

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 of this programme is to demonstrate the entire package at the 200 kW scale firstly in the CRL Energy laboratories and then possibly at a remote site after the completion of the programme – possibly as part of a distributed generation package. 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

Having completed the design and construction of the fluidized bed gasifier, an immediate concern was in developing a method to safely and reliably 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 continue to be numerous start-ups and shutdowns while we commission, optimise and experiment with different syngas cleanup technologies. Originally this was achieved using a set of electrical heating elements fitted to the outside of the ceramic casting that forms the fluidised bed of the gasifier. Although this system worked well for a time, progressive element failure led to a situation where it was not possible to pre-heat the bed sufficiently in order to reach ignition temperatures. In our current method the electrical elements are used to heat the bed ceramic liner whilst the bed material is pre-heated to 400°C in an external auxiliary chamber prior to being introduced into the gasifier vessel.

Several hours of running in combustion mode are required in order to slowly and evenly heat the ceramic liner of the gasifier to a uniform operating temperature. Conversion from combustion mode to gasification mode is readily achieved.

Results of testing to date have shown that good quality gas can be produced at 900°C at moderate rates of steam injection. The use of steam injection into the freeboard, as well as into the bed has the effect of improving gas quality in terms of increasing the hydrogen concentration in the syngas by a few percentage points. Increased rates of steam injection, increased bed temperatures and coal feed rates do not have a significant impact in terms of improving hydrogen concentration.

The Delta V instrumentation control system from Emerson Process Technology is proving to be very reliable, easy to programme, easy to use and flexible. 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.

Particulates are removed in two stages; initially in a high efficiency cyclone (it captures approximately 95% of the particulates) and then in an ejector venturi scrubber in which the syngas is quenched and any remaining particulates, tars and condensables are removed.

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 it was envisaged that we would design and use a small scale conventional packed column absorption tower that utilizes 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 we intend using a proprietary sulphur scavenger to eliminate H_2S from the syngas stream. This component is currently undergoing initial testing.

Two water gas shift reactors have been designed – one to shift the entire gas flow and a smaller one to handle a slipstream of the gas. Both are based on a high temperature water gas shift catalyst. The intention is to initially divert a slipstream of syngas through the small, single bed, scale reactor and pass the shifted gas to a small palladium membrane based hydrogen purification system. This system is already being successfully used to generate alkaline fuel cell grade purity hydrogen from syngas produced (by our research partners IRL in another project) from a small scale methanol reformer. Although unable to handle more than a fraction of the syngas from the current gasifier, the aim is to provide a working example of the entire coal/ fuel cell/ electricity package for stakeholders.

In order to separate pure hydrogen from the other remaining constituents of syngas emerging from the large scale shift reactor, it is likely that the proven method of Pressure Swing Adsorption (PSA) will be used. A PSA unit best suited to match the requirements of the gasification system has been selected. The flow rates from our gasifier are at the extreme lower end of the operating range of the smallest commercially available PSA. There appears to be a lack of readily commercially available hydrogen separation units at the distributed scale at which we are working.

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.

The role of coal in a hydrogen economy in New Zealand:

It is clear that coal is well placed to provide New Zealand with the hydrogen it will need during a transition towards a renewables based hydrogen energy economy – but there was not, until recently, a realistic roadmap of milestones and timelines for the transition. The following section describes some of the pertinent factors.

While it is generally accepted within the international community that the ultimate aim is to base the hydrogen economy entirely on renewable energy sources there will be a transitional period during which hydrogen production will be mainly from fossil fuels. The reasons relate to resource availability and cost of production and are as valid in New Zealand as they are elsewhere.

It is also generally accepted that the really big demand for hydrogen will not occur until the purchase and operation of fuel cell vehicles becomes commercially viable. For New Zealand it is predicted that the growth in fuel cell vehicles will increase rapidly from 2025 onwards and that by 2050 over 90% of the fleet will be fuel cell vehicles. This fleet will consume between 1.2 and 1.75 million tonnes of hydrogen in the year 2050. This corresponds to 140 to 210 PJ of energy and approximately 10 to 15 million tonnes of coal, (depending on the production technology), will be consumed in order to produce it. Prior to then, other applications in small scale distributed generation and larger scale electricity generation will become established and will play an important role in raising public awareness and acceptance of hydrogen.

There are sufficient known reserves of coal to meet over 400 years supply at the 2050 demand level for transport hydrogen. Conversely for natural gas, Ministry of Economic Development figures assume ongoing discoveries at the rate of 60 PJ per annum - sufficient to meet one to two months' hydrogen demand at 2050 levels. If the hydrogen were to be generated by electrolysis using electricity produced from renewables an estimated 280 to 420 PJ of energy would be needed. Recent Ministry of Economic Development predictions for future economically viable untapped electricity generation indicate only one third of this amount (130 PJ) will be available from these sources.

Estimates of the costs of delivering hydrogen to the future hydrogen fuel cell transport fleet indicate that coal based hydrogen production and delivery systems, including allowance for carbon capture and sequestration (CCS), may be significantly lower than those associated with renewable based production. Comparisons of the total supply chain costs of the gasoline and hydrogen needed to provide equal vehicle mileage when consumed in a gasoline hybrid electric vehicle or a fuel cell vehicle also suggest the coal based hydrogen generation option is a very competitive one. These studies are based on the assumption that the massive international R and D programmes currently in progress are successful in reaching certain well-established targets in terms of reduced costs of fuel cells and improved on-board hydrogen storage capability.

From the above considerations, it appears extremely likely that the pathway to a hydrogen economy will initially involve the use of syngas for electricity, liquid fuel or chemical production. Subsequently, as the transport fleet converts to fuel cells and demand grows, increasingly large portions of the syngas stream will be slip-streamed off and passed through a cleanup line capable of producing fuel cell grade hydrogen. Ultimately, predicted demand levels will require construction of several large plants dedicated primarily to hydrogen production. CCS capability will be integrated into these plants.

It is envisaged that there will be at least three types of coal powered application in a fully fledged hydrogen based energy economy. One is to meet the energy demands of small remote communities, one is to meet the demands of a large industrial complex and one is to produce the bulk of the hydrogen required by the transport fleet.

In the small scale off grid distributed generation application, electricity is likely to be produced by a combination of fuel cell and gas engine/turbine technologies. Economic analysis suggests that the viability of such applications will depend heavily on recovery and utilisation of the low-grade heat produced. This could, for example, be used for heating a glasshouse, cleaning a dairy shed or heating a swimming pool. Although the coal consumption associated with this option may be small, this is viewed as an essential early step on the transition towards hydrogen and an invaluable tool in generating public acceptance of coal in a future hydrogen economy.

The energy demands of a large industrial site could be met by a tri-generation (electricity, heat and hydrogen) operation in which electricity is produced by solid oxide fuel cells with the heat recovered from the exhaust of the fuel cell being used to meet the thermal requirements of the plant. Hydrogen produced may also be used to run the plant's fuel cell transport fleet. A first pass assessment for a hypothetical plant generating 40 MW thermal, 20 MW electrical energy and sufficient hydrogen to power 200 light vehicles suggests this may well be a viable option in New Zealand. Further, more in-depth techno-economic evaluations of this option are warranted.

The third application will be used to produce the bulk of the hydrogen required by the transport fleet using large-scale coal-powered centralised multiplexes. These plants will also simultaneously co-produce electricity. Ultimately several of these plants will be required in New Zealand. The first plant of this type is likely to arise in a modular fashion around an existing core gasification based facility – most probably a combined gas and steam turbine (IGCC) facility.

For plants of this size it is important to consider issues around bulk hydrogen distribution and several different production/distribution configurations may be envisaged.

- The first is exemplified by a plant located in the Waikato/Auckland area near a large demand base, utilising local sub-bituminous coal and sending the hydrogen through 600 km of large capacity pipeline to a series of 400 fuelling stations servicing 2 million vehicles. The plant is likely to utilise the sub-bituminous reserves of the Waikato region – estimated to be sufficient to meet 2050 demand levels for 40 years. Based on a recent US techno-economic study we estimate a total delivery cost at the forecourt of $US1.64 per kilogram of hydrogen. This is made up of $US0.77 per kg production cost, $US0.31 per kg distribution, $US0.39 dispensing and a CO_2 capture and sequestration cost of $US0.18 c per kg. A typical vehicle refuelling will require 3 to 4 kg of hydrogen – sufficient to give a range of 300 to 400 kilometers.

- Under a second scenario, a Southland/Otago gasification-based plant would produce hydrogen, and possibly also electricity. While Southland/Otago region contains the bulk of the coal reserves, it is removed from the main population centres of the North Island. The hydrogen would be transported in a gaseous form to these high demand centres via a dedicated pipeline spanning the length of New Zealand. Estimates are that this option will deliver hydrogen to a motorist in Auckland at a cost of $US2.15 per kg of hydrogen. The cost increase over the Waikato based scenario ($US1.64 per kg) relates primarily to the high capital cost of the 1600 km pipeline. It is also technically possible to transport this hydrogen in liquid form by rail ($US2.64 per kg) or by using dedicated coastal shipping tankers although at an estimated $US4.70 per kg this appears economically unviable.

- A third configuration again has the gasification plant(s) based in the lignite fields of Southland and Otago. The plant would generate electricity only which would be transported through an upgraded national grid to the refuelling stations or local facility where hydrogen production via electrolysis would occur. The use of gasification to produce the electricity has many advantages over traditional plant based on sub-critical or super-critical steam cycles. This includes increased efficiency, lower cost of CCS and the inherent flexibility offered by production of syngas. This option is estimated to deliver hydrogen to the northern motorist at $US2.86 per kg.

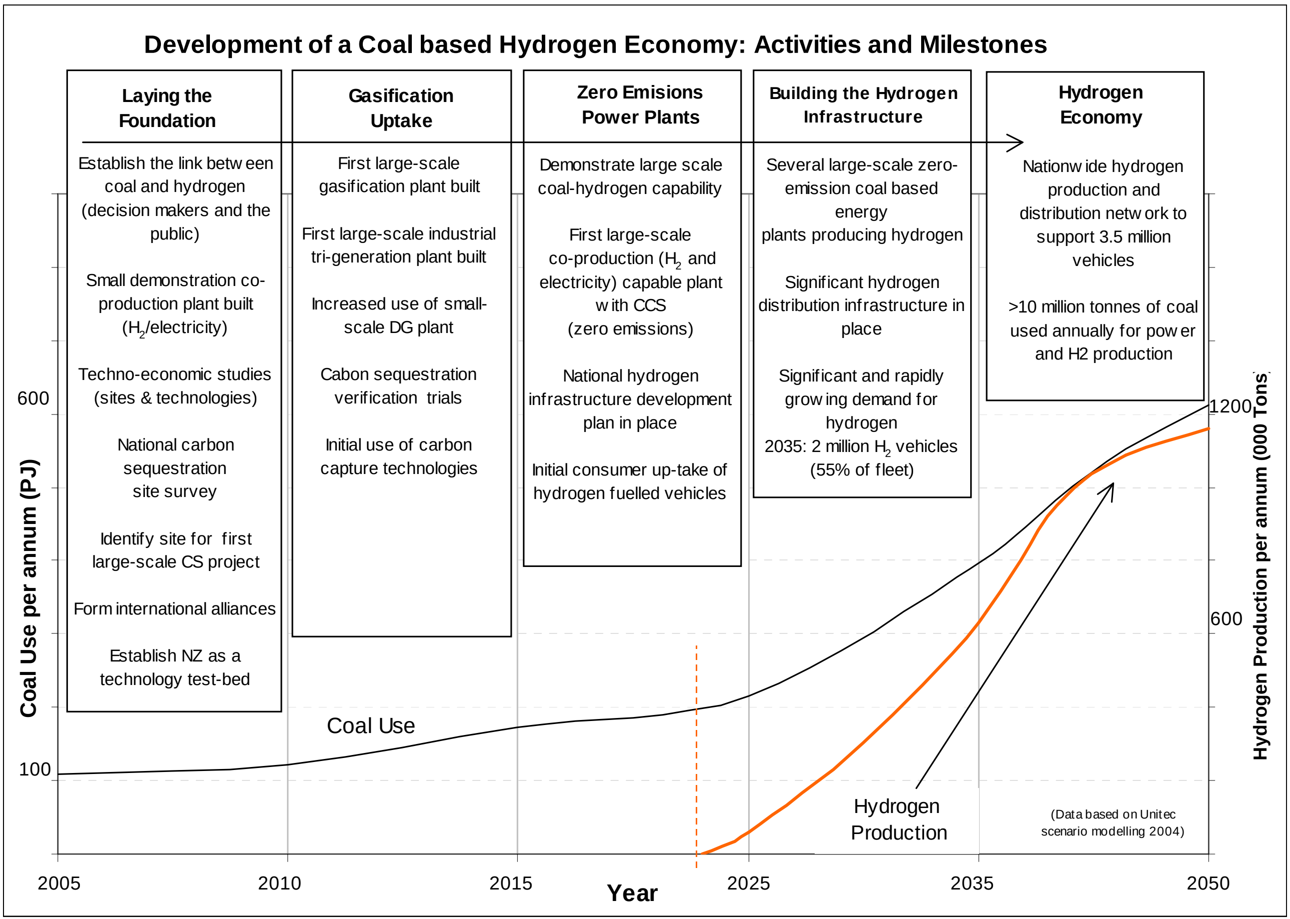
- A fourth scenario would again utilise the large lignite reserves but in this case the syngas resulting from gasification would be converted to a hydrogen rich, low carbon synthetic liquid fuel. This would be shipped to the demand centres using conventional liquid fuel infrastructure at which point it would be further processed to release hydrogen. This is the least technologically developed option but is presently receiving a great deal of research investment in the US.

In order for a hydrogen economy to develop, the delivered hydrogen cost must be competitive with other fuels. The hydrogen costs quoted above correspond to a fuel cost per kilometre driven of between 0.66 and 1.14 times that of a current gasoline engine vehicle.

It is likely that a coal based hydrogen economy will utilise some combination of the above production/distribution pathways. New Zealand specific in-depth techno-economic studies are required in order to identify the most economically viable configuration.

All three application types – remote communities, industrial site and large scale hydrogen multiplex will produce CO_2 as a co-product. Large scale plants – each consuming 7,000 tonnes of coal per day and producing 1,200 tonnes per day of hydrogen - will be required to sequester approximately 6.5 million tonnes of CO_2 per annum. This highlights the importance of identifying and quantifying the available geological sequestration capacity in New Zealand. International studies have shown that worldwide there is sufficient geological sequestration capacity to sequester for almost 400 years at current CO_2 production rates.

From all of the above, the following coal based pathway to a hydrogen energy economy may be identified:



Cutting across all time periods are issues relating to public outreach, education of decision makers and other stakeholders and the development of standardised, internationally accepted codes and practices. It is particularly important that in order to create the enabling environment for a hydrogen economy, policy and decision makers are well-informed at an early stage.

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". 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 200 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.

A detailed roadmap has been produced identifying key milestones and timelines that must take place in order for coal to play an important role in New Zealand's future hydrogen energy economy.

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