# LOW ENTHALPY ABOVE-GROUND GEOTHERMAL & ALLIED TECHNOLOGIES (AGGAT) – A RESEARCH AGENDA

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**Keywords:** *Above-ground, geothermal, low enthalpy, Organic Rankine Cycle, waste heat, clean energy, electricity, power generation, heavy engineering, research roadmap*

## ABSTRACT

Low enthalpy resources can be converted into electricity using well proven Organic Rankine Cycle (ORC) technology, which has been widely adopted as the preferred technology for converting low temperature geothermal and waste heat resources into electricity. New Zealand is fortunate to have a highly accessible geothermal resource, a significant history in geothermal technology development and a capable heavy engineering fabrication and manufacturing industry. These attributes, combined with a fast emerging low enthalpy export market, provide an ideal basis for NZ industry to expand its product offerings in ORC technology.

The New Zealand Heavy Engineering Research Association (HERA) has been working with industry partners and research providers to develop above ground technology solutions for this market, specifically targeting low enthalpy geothermal and waste heat resources for effective conversion into electricity using ORC technology. This activity has highlighted the need for a structured approach to above ground geothermal and allied technology research and development, which industry and partners have been working to establish.

This paper addresses the issues, options and challenges faced in progressing an Above Ground Geothermal and Allied Technology (AGGAT) research agenda.

## 1. INTRODUCTION

The global demand for cheaper energy alternatives has driven all involved in energy processing, individual and corporate entities alike, to pursue resources and opportunities to fill this gap. Rising fuel prices, a growing emphasis on environmental sustainability and the impact of a 'clean and green' perception have further intensified the societal support for the promotion of clean energy initiatives. Current growth trends in clean energy technology have been following double digit growth rates (Pernick et al, 2012) with increasing R&D investment in the industrialised and developing nations (PEWS, 2011). Along with research interest in wind, wave and tidal and solar, geothermal energy has attracted significant attention for research and development (R&D) as part of the fast emerging clean energy sector.

New Zealand (NZ) enjoys an abundant geothermal resource with highly active geothermal fields located in the Taupo Volcanic Zone (TVZ). Since the 1960s, NZ has played an increasingly active role in the development of its geothermal resources which now accounts for 13-14% of all electricity generation nationally (White, 2012). NZ has a national target to generate 90% (MED, 2011) of its electricity from renewable energy sources by 2025 which stood at 79% in 2011 (Parata, 2011) and a 50% reduction in greenhouse gas emissions from 1990 levels by 2050.

Significant geothermal developments from national electricity providers such as the Mighty River Power Nga Awa Purua project (140MW) (MRP, 2011) and Contact Energy Te Mihi project (166MW) (EHE, 2012) have been undertaken with more projects in the pipeline for future developments. With the base strength of geothermal capability as demonstrated in NZ, a national strategy is in place to progress the case for NZ based geothermal offerings that will showcase NZ to be a major contributor to the renewable energy development efforts in a global context. Geothermal NZ, an umbrella term for collaborative efforts among NZ geothermal groups, is collectively advancing this strategy with NZ government support (NZTE, 2011).

The Heavy Engineering Research Association (HERA) of NZ is aligned with the efforts of Geothermal NZ. HERA is making efforts to advance a low enthalpy heat to electrical conversion programme that will develop NZ geothermal capability in binary plant technology. This is to be achieved through a long term R&D programme in partnership with research providers and industry members.1.2 Subheading

## 2. HEAT TO ELECTRICAL CONVERSION

Converting heat to electricity from geothermal resources is achieved with three commonly used power conversion technologies;

- Dry steam which uses steam directly for power generation,
- Flash steam which converts pressurised water into steam to be used for power generation and
- Binary cycles in which hot water from geothermal source heats up an organic fluid with a lower boiling point to be used for power generation.

Dry steam plants are at the high temperature end (high enthalpy) while binary cycle plants are applied at the lower temperature end (low enthalpy) of the energy scale. Low enthalpy is typically defined as geothermal energy available in the temperature range of 0-150°C and is widely available in NZ (EMS Ltd, 2011). Common low enthalpy resources can be found in:

- Abandoned hydrothermal oil wells

- Hot water from geothermal springs,
- Spent liquid brines with residual heat value from geothermal steam plants,
- Hot water river discharges and even
- Waste heat lost from process pipes in processing plants.
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Low enthalpy utilisation must be recognised for its critical role in enhancing the perception of minimising energy waste and maximising energy efficiency. This is particularly true for energy intensive processing sites which have a lot of low temperature process heat being wasted through loss to environment or discharge facilities. Productive use of these resources can significantly alter the operation dynamics for a processing facility and its image in society. The portfolio of advantages associated with low enthalpy technology includes:

- Increase plant efficiency
- Reduced operating costs (parasitic loads)
- Reduced carbon footprint
- Recognition for supporting clean energy initiatives

### 2.1 Binary cycle

A binary cycle gets its name from the nature of its operation, which requires heat transfer between two fluids, one being the primary heat source fluid (e.g. geothermal fluid), while the other is the secondary organic based operating fluid. In essence the organic or the binary fluid does the work of dry steam in a steam plant but at a much lower temperatures. This is owing to the lower boiling points available from organic fluids. Widely used in industry, binary cycles are currently the technology of choice when it comes to low enthalpy conversion. A representative binary cycle is shown in Fig. 1 below. A typical binary cycle undergoes much the same process as a high enthalpy power plant and contains the following unit operations:

1 – Organic fluid is heated by the primary heat source in a heat exchanger to its saturation point

2 – The liquid in its saturated state enters and undergoes expansion in an expander /turbine device being converted to gas in the process.

3 – The expander/turbine shaft rotates due to the force of fluid expansion converting pressure into kinetic energy. The shaft is coupled to a generator which generates electricity through the process due to shaft rotation.

4 – The gas is then cooled down to its saturation temperature and condensed in a condenser

5 – The condensed liquid is transferred using a liquid pump back to the heat exchanger for heating and repeat the cyclical process.

Variations exist in the process such as adding a recuperator prior to evaporation for preheating. This recuperator could be placed before the condenser to remove any superheat from the liquid. Similarly this may not be required if the fluid is being run partially wet in the turbine. This can however have degrading consequences for the turbine due to internal erosion if not managed carefully.

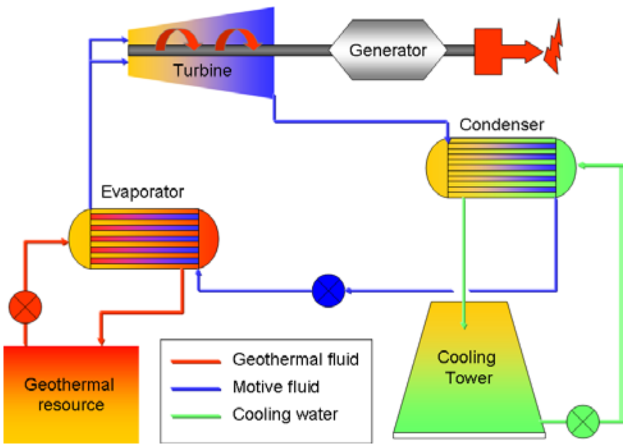


**Figure 1: A representative binary cycle**

The most commonly used binary cycle is the Organic Rankine Cycle (ORC). It is based on the Clausius-Rankine (steam) cycle and is its variant due to the different range of operating temperatures. Other competing cycles such as the Kalina cycle and Stirling cycle have sporadic global applications but are still partially in the process of gaining industrial credibility. Some of the low enthalpy power conversion technologies are compared in the technology review provided by Gazo & Lind (2010).

### 2.2 Issues with binary plants

<u>2.2.1 Capital costs</u>

Whilst highly popular, binary plants such as ORC are still not as widespread in low enthalpy industrial applications. Initial capital costs (~$3000/kWe) are a deterrent and despite being well established; binary plants are still regarded as new commercial technology and are less well known among project financiers (Gazo and Cox, 2011).

<u>2.2.2 Binary cycle efficiency</u>

It is also the common perception and truly so that the efficiency of binary plants drops with smaller scale of operation. This makes the low enthalpy opportunities an unattractive market to invest in since the majority of the low enthalpy resources are likely to have limited heat resources dictating smaller operating scales.

<u>2.2.3 Plant design</u>

Current binary plant designs are customised to specific resource conditions and this approach has been adopted by the major plant providers. The designs are not yet at the stage where they can provide standardised solutions. Attempts have been made in literature to present optimum design criteria (Hettiarachchi et al., 2007, Franco et al., 2009) however this is still an area for active research.

Research and development in low enthalpy geothermal (LEG) technology is ongoing. NZ has an excellent geothermal background and the capability to be part of, and contribute significantly to, this R&D agenda. The outcomes will not only benefit NZ with new export streams but also the binary plant market through providing affordable product and technology options.

## 3. LEG R&D PROGRAMME AT HERA

HERA is an active proponent for advancing the status of above ground low enthalpy geothermal (LEG) technology in

NZ and in collaboration with partners leads an active LEG R&D programme. However, since low enthalpy can also be derived from non-geothermal sources such as industrial waste heat and since the products and plant designs being focussed on are modular, the agenda for LEG technology has incorporated these as allied technologies into the programme framework. Collectively the programme has morphed into the Above-Ground Geothermal and Allied Technologies (AGGAT) R&D programme.

This programme is industry driven and industry supported. HERA is an industrial research association providing research management, advocacy, training, advisory and information services to its 600+ strong metals engineering industry membership. Through this programme, participating industry members will develop AGGAT products for niche export markets.

### 3.1 Research agenda

The research agenda for AGGAT is built around the following goals:

- To provide affordable and cost-competitive technological options in the AGGAT linked industry sectors
- To enable NZ achieve key player status in clean energy development through AGGAT R&D
- Build and maintain a national-level AGGAT research platform for continued innovation and growth
- Foster relationships and collaboration with international researchers, institutes and developers involved in AGGAT research

### 3.2 NZ manufacturing & fabrication capabilities

To showcase the geothermal expertise available within the heavy engineering sector in NZ, HERA has created a geothermal capability register which is proactively maintained and periodically updated (Inskip, 2010). This resource is available through the HERA library. The register categorises member as well as non-member companies according to their geothermal expertise making a convenient means for connecting the company (supplier) with a customer. Companies are categorised according to the following categories:

- Geotechnical exploration
- Planning
- Design
- Heavy Engineering Fabrication
- Electrical control systems
- Packaged pumps, services, pipes, tanks
- Plant operation
- Education / Training

An example of engineering workmanship of one of our member companies, Fitzroy Engineering for one of the major NZ geothermal developments is shown below in Fig. 3. Fitzroy Engineering was responsible for the mechanical installation of machinery equipment and piping for stage 2 expansion of the 60MW Mokai geothermal power station for Tuaropaki Power Company Ltd at Mokai, Taupo, NZ.

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Geotechnical Exploration | Resource Evaluation/ Feasibility/ Business Case | | | | | ■ | | | ■ | | ■ | | | | | ■ | | | |
| | Drilling | | | | | | | | ■ | | | | | | | ■ | | | |
| | Modelling Geology/interpretation of Geothermal fields | | | | | | | | ■ | | | | | | | ■ | | | |
| | Surveying & Site Set-out | | | | | | | | | | | | | | | ■ | | | |
| Heavy Engineering Fabrication | Coded boilers & pressure vessels | | ■ | ■ | | | | ■ | | | | | | | ■ | | | ■ | |
| | Coded Pipe Spooling | | ■ | ■ | | | | ■ | | | | | | | ■ | | | ■ | |
| | Heat Exchangers (plate type) | | | | | | | ■ | | | | | | | | | | | |
| | Heat Exchangers (shell & tube) | | ■ | | | | ■ | | | | | | | | ■ | | | ■ | |
| | Separation Plant | | ■ | | | | ■ | ■ | | | | | | | ■ | | | ■ | |
| | Condenser Manufacture | | | | | | ■ | ■ | | | | | | | | | | | |
| | Cooling Towers | | | | | | ■ | ■ | | | | | | | | | | ■ | |
| | **COMPANY** | A & G Price | Acme Engineering | Services | AECOM NZ | Aerial Surveys | Engineering | Amtec Engineering | ARANZ Geo | Baker Cranes | Beca | Bremca Industries | Brown Brothers | Cardno | Century Resources | Cheal Consultants | Concord Technologies | Contract Engineering | CRL Energy |

**Figure 2 – Sample summary categorisation of companies according to expertise in the geothermal capability register (Inskip, 2010, HERA)**

**Figure 3 - Mechanical installation of machinery equipment and piping for Mokai geothermal power station at Mokai near Taupo in NZ undertaken by Fitzroy Engineering (Lovell, 2008)**

### 3.3 HERA activities & progress

3.3.1 Industry development roadmap

The process that HERA uses to develop its industry is illustrated in Fig. 4 and is derived from the industry development roadmap (Inskip, 2012). It firstly highlights the transfer of information from the market to the company which is interested in that particular market. This market information identifies the development needs for the company which define the R&D requirements. These requirements form the basis of research activity which HERA manages on behalf of the industry, which depending on the requirements, is undertaken by a suitable research provider/s. The research outcomes are fed back to the company which are used to develop products to enter the market. This back and forth process is continuous and iterative as ongoing innovation and research activity are typically necessary to ensure products are match fit for the market.

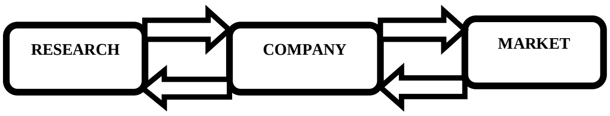


**Figure 4 – HERA industry development process**

3.3.2 ORC demonstration plants – Pilot scale project

Based on the industry development roadmap, HERA invited member companies to participate in the low enthalpy AGGAT development programme. Market analyses were carried out by HERA for the global geothermal (Obert, 2010) and low enthalpy waste heat (Wucherer, 2010) markets to gain an understanding on current market dynamics and prospects.

This is an industry driven development programme and has the primary objective of setting up at least two 250kW electrical (kWe) ORC pilot scale plants for demonstration purposes; one with a geothermal source and one with a waste heat source. The plants will be market ready exportable products. While the member companies have excellent engineering and fabrication capabilities, by being involved in this programme they are taking the step of advancing from the status of contractors with a range of experience, including geothermal, to manufacturers of binary plants.

The research element of the program will deliver a design tool / standard that member companies can use as a design aid in designing their plants before they enter the construction, monitoring and operation phase. This task is being undertaken by a research team in the Mechanical Engineering department at the University of Canterbury, NZ. The tean has also completed a state of the art review on ORC technologies (Jung & Krumdieck, 2012).

A workshop was held by HERA on 22nd March 2012 to present to project members and the wider geothermal community the research deliverables and an update on the project progress. The workshop provided an opportunity for networking and collaboration between research providers, key stakeholders and industry representatives. Feedback on the project and next steps was also received from the workshop attendees.

The industry development team at HERA has located a suitable waste heat resource site to host a 250kWe ORC plant. A few options for a hydrothermal location are being considered simultaneously for the geothermal based 250kWe ORC plant. Preliminary process design characteristics of ORC plants for these sites have been completed at the University of Canterbury which are being considered by the engineering teams of member companies. The member companies are now entering the detailed design stage of mechanical drawings of the plants which is expected to be complete by June 2013.

HERA recently organised a trade delegation to the US in which member companies involved in the AGGAT programme participated. The delegation visited major manufacturers, research labs and product suppliers in the ORC market including the Rocky Mountain Oilfield Testing Centre (RMOTC). The group returned with insights into the research, manufacturing and market opportunities in the USA. As a result, opportunities for international collaboration are being considered which will benefit progress significantly in the AGGAT R&D programme. Reports and presentations on the US delegation are available through the Industry development division of HERA.

3.3.3 Control systems research - HEERF PhD project

As part of the AGGAT programme, a Heavy Engineering Educational Research Foundation (HEERF) scholarship has been granted for a PhD project in control systems research to the department of Chemical & Materials Engineering at the University of Auckland. This project will look at developing the IP for control systems in ORC plants for effective control, monitoring and operation. It is expected that this will deliver ORC plant IP in a control systems package for HERA that can be then made available to participating member companies.

3.3.4 AGGAT research roadmap

HERA has prepared a draft research roadmap which informs the industry development roadmap. The research roadmap outlines the research framework, objectives and research questions as a pathway to strategically steer AGGAT efforts. An inclusive approach to AGGAT research means that it includes other thermodynamic cycles such as the Kalina and Stirling cycle. The roadmap incorporates other forms of heat resources such as solar and hybrid options and also includes plant performance at different scales of operation other than pilot scale. The dynamics associated with technology integration and system performance under these circumstances will be investigated as part of this research roadmap. A breakdown and categorisation of the research framework is provided in Fig. 5 along with their position in development stages as active (green), next stage (blue) and long term (red).

around existing technology to support the development and manufacture of expanders and turbines independently. Given the current global environment with newcomers entering this field, the timing will remain urgent justifying timely conduct of AGGAT research and development. Regardless, this is an agenda that NZ needs to pursue to be a part of the international geothermal stage.

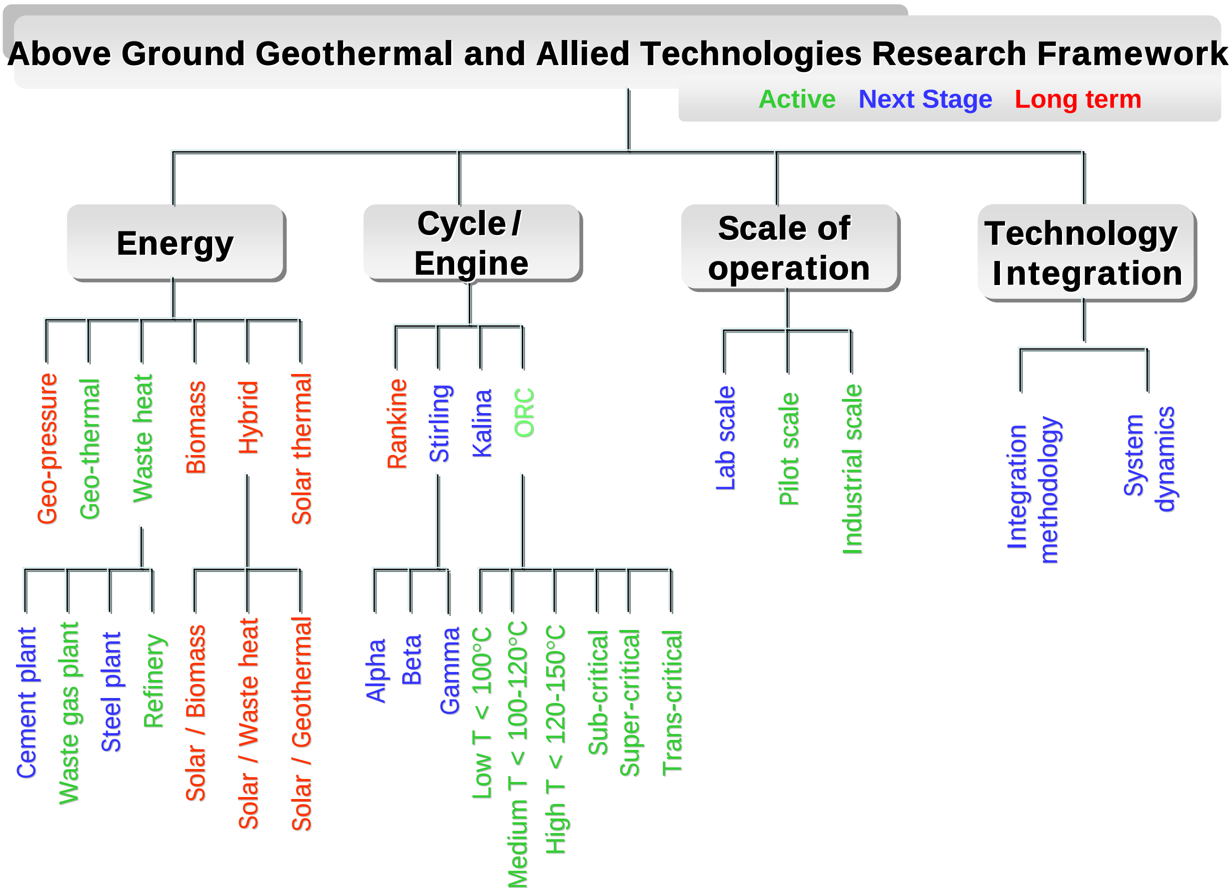


**Figure 5 – Breakdown of the research framework for the AGGAT research roadmap**

HERA recently submitted an application to the NZ Ministry of Business, Innovation & Employment (MBIE formerly MSI) under the science funding round of April 2012. Acceptance of this application is critical to the advancement of the AGGAT programme. A sizable consortium of industry co-funding as well as research leaders supporting specific research aims is ready to proceed forward subject to the outcome of this application. HERA members are committed to advancing the AGGAT technology development agenda which will bring NZ to the forefront of binary technology development.

## 4. CHALLENGES ON THE PATH FORWARD

HERA is a pioneer organisation in NZ in promoting the AGGAT research agenda. Conceptual inroads into the general opinion sphere for binary cycle development still need to be developed to gain ‘buy-in’ for an AGGAT agenda. This will be possible with first successes coming through in the pilot scale projects. A major deterrent in this regard is the perceived notion of turbine manufacturing requiring complex infrastructure for design and manufacturing. A research platform will need to be built

## 5. CONCLUSIONS

Low enthalpy AGGAT research and development needs to be established, promoted and advanced through developing a collaborative research and manufacturing pathways in NZ

HERA actively leads R&D in low enthalpy above ground technology and through collaborative partnership with research providers and industry members is progressing to build at least two 250kWe ORC demonstration plants in NZ

NZ has key capabilities in research and manufacturing that need to be supported to deliver exportable AGGAT products

International collaboration at an early stage will help support the pace and direction necessary to meet roadmap and timeframe requirements

The AGGAT vision is to strategically position NZ to be recognised as a key contributor in the framework of global efforts on clean energy

**ACKNOWLEDGEMENTS**

HERA acknowledges the active support of member companies involved in the AGGAT research programme through their co-funding contributions.

HERA acknowledges the research team headed by Associate Professor Susan Krumdieck and their lead researcher Dr. Jung HyungChul for their contributions so far to the AGGAT programme through the TechNZ project.

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