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# Above Ground Geothermal and Allied Technologies (AGGAT) Paving the Research Roadmap

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## ABSTRACT

Above Ground Geothermal and Allied Technologies (AGGAT) is an initiative born out of the need to represent and build a technological research and development base for above ground technologies in power generation. New Zealand (NZ) holds significant authority internationally in below ground research activities which is now being complemented with a parallel arm to support above ground research activities through the AGGAT programme.

The Heavy Engineering Research Association of NZ has initiated a series of national efforts to launch this programme which has been in development for 4 years now and took a major step forward with government funding last year allowing us to partner with major universities across NZ in our research and development roadmap. This paper presents on the programme strategies, the drivers, its achievements and associated challenges that are being overcome to move the programme forward. A lot of the international research in above ground technologies is disparate. One of the primary AGGAT objectives is to bring them all together under the AGGAT umbrella so as to maximize output through leveraging for the industry as a whole. Hence this paper also presents on future AGGAT activities and our strategies to align international research with our objectives to unify and maximize its output.

## 1. INTRODUCTION

The Above Ground Geothermal and Allied Technologies (AGGAT) programme was initiated in 2012 to set up a platform for uniting technological initiatives supporting clean energy developments. This was borne out of the need to foster clean energy initiatives at the behest of the Heavy Engineering industry of New Zealand which considered this to be a strategic area of involvement for industrial growth. The driver for this need comes from the Industry Development Roadmap proposed by Inskip, (2009) which identifies market needs to consult with NZ heavy engineering companies and translates the research requirements into projects. This process has been followed to create a research agenda for above ground technologies. A case for this research agenda has been presented previously by Habib et al. (2012).

The classification of 'Above-ground' technologies arises due to the very strong focus in New Zealand on below ground research in geothermal and reservoir engineering. Whilst the focus is deservedly greater on below ground research in NZ considering the abundance of geothermal resources in NZ geology, the need for simultaneous development of energy processing technologies has been expressed within NZ geothermal communities. There is considerable evidence demonstrated through local fabrication and engineering capabilities and research and development (R&D) efforts for development potential in above ground technology in NZ which could potentially also be extended beyond its borders to invite international collaboration. However a strategic framework to facilitate this has not yet been formulated that could unite and advance the case for above ground technologies associated with power generation from heat resources such as geothermal brines. The need for such a strategic focus is based on the development opportunities that exist in the low enthalpy range (below 150°C) of heat resources such as low temperature geothermal brines and waste heat surplus such as generated from industrial processing plants.

Recently market assessments were completed by the Heavy Engineering Research Association of New Zealand (HERA) that investigated the market scope and needs for low enthalpy power generation, Obert (2010), Wucherer (2010). These assessments supported the view that enormous potential remains untapped in the global pool of low temperature geothermal and waste heat resources which is gaining uptake by new entrants in this market offering energy conversion solutions at a premium price. These reports detail market segments that have the potential to provide a number of niche opportunities and also herald the need for innovation in existing energy conversion technologies to increase power output and performance derivable from them. Significant support has been garnered at a national level within NZ for such a programme that will not only lift NZ research and development capability in clean energy initiatives but also develop a platform for global collaboration in clean energy which is fast becoming a key area of concern for our future sustainability. This is a research strategy paper outlining the roadmap for our current clean energy programme called the 'AGGAT Science Base'.

## 2. CONTEXT AND FRAMEWORK

New Zealand is well represented in its geothermal activities by the New Zealand Geothermal Association (NZGA), a non-profit and non-political organization to encourage, facilitate and promote geothermal related research and development activities. Its off-shore activities are represented and promoted by Geothermal New Zealand an association which is marketing focused and aims at promoting the NZ Inc. brand. The positioning for AGGAT activities in this mix is to support research requirements of industry in relation to above-ground technologies that are related to the field of power generation and in this context provide a framework for their development in NZ.

Bringing a number of disparate technologies together under one banner with alignment to one objective of delivering energy in a 'smarter, faster and cheaper' way has been a challenging task. However in submission to this intent, the said technologies are considered 'allied' to the concept of above-ground technologies. So for example, a hybrid form of low enthalpy heat resource that utilizes waste heat from an industrial processing facility and PV solar panels is allied to the generation of electricity from low enthalpy geothermal brine. Hence these technologies are allied under the umbrella term of 'Above Ground Geothermal and *Allied* Technologies'.

To begin with the development of a suitable framework, the key requisites are necessarily stretched to broaden the inclusiveness of the AGGAT research framework which has been displayed schematically in Fig. 1 below. Through careful deliberation on research scope and development strategy, the following requisites were selected to be most relevant which have been further sub-classified in time in order of priority and our ability to address them.

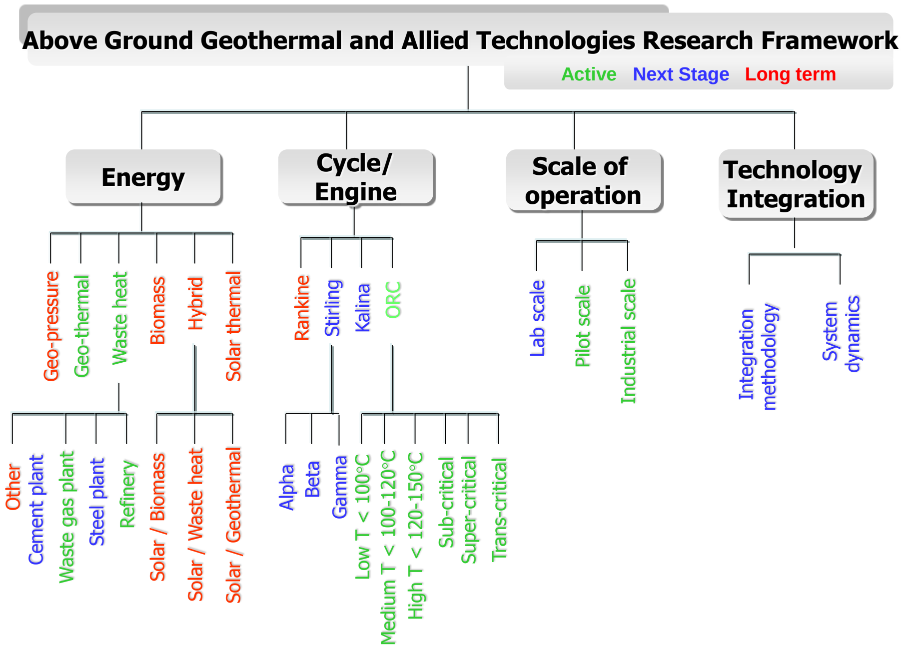



**Figure 1: Schematic representation of the AGGAT research framework**

### 2.1 Source of energy

As pointed out earlier, low temperature geothermal and waste heat are of primary interest in the spectra of energy sources available due to their relatively greater abundance and their immediacy attached to the scope of this work. However other forms of energy that can be considered renewable and will be valuable to assess in this research are geo-pressure, biomass, solar-thermal as well as hybridized forms of alternative energy sources which use similar technologies. This list is by no means meant to be exhaustive and ongoing developments in the programme may well uncover other energy sources that could be relevant to the objectives of this programme.

### 2.2 Type of cycle/engine

The scope of existing thermodynamic cycle and engine variants has been restricted to non-combusting processes. The sub-critical Organic Rankine Cycle (ORC) is perhaps the most well-known and industrially accepted non-combusting technology for energy conversion at low temperatures into electricity. This along with its variant cycles (trans-critical, supercritical etc.) is a core focus given its market-end popularity and potential available for further research and development. Through literature and media impressions, the Kalina cycle has been subject to various interpretations concerning its ability to provide an alternative to the ORC and has had varying degrees of commercial success in some countries based on their national drivers and policies. The Stirling cycle, although still shy of commercial success, is a promising technology and a close ally to the ORC developments. The Clausius-Rankine cycle on account of bearing numerous similarities to the skeletal ORC process is expected to share benefits from some of its innovations and hence has also been brought in the scope for this reason albeit as part of long-term strategy.

### 2.3 Scale of operation

The need of this programme dictates requirement of a pilot scale facility (100-250kW) that will allow experimental testing to take place whilst also providing the necessary confidence in field-hours to claim long-term operational stability. Industrial trials will take the form of multiple installations of the same sized module innovation or conversion of the innovation to a higher sized module (>500kW). However to 'de-risk' expensive installations and to fast-track delivery of preliminary results, a lab scale facility (<20kW) has also been considered necessary. This is of particular benefit to research providers where testing at this scale is more likely to be a feasible option.

### 2.4 Technology integration

This requisite of the programme scope acknowledges the importance of understanding integration challenges within the different unit operations of an energy conversion process and the interaction with the surrounding operational environment. There will be a need to understand the impact of any innovation in a technology on its ability to systematically and successfully integrate within a process and within an operational environment through monitoring of its system dynamics. These have been classed for investigation under integration methodology and system dynamics.

In this framework, the research and development efforts are divided into strategic research themes that best represent major research interests in energy conversion technology and can be classified distinctly enough to minimize overlap of research efforts between themselves. The standard power generation cycle/engine is dependent on the following principles and/or operations:

- Arrangement of the energy conversion process module
- Heat extraction and exchanging operation
- Mechanical to electrical energy converting operation
- Fluid chemistry and thermodynamic properties
- Control and instrumentation logic

Most of the energy conversion technologies/models are a derivative or variant of the above principles and/or operations. The research themes proposed are in accordance with these principles and are placed in the confines of the programme requisites. The structure of this relationship is depicted in a rhombic format in Figure 2 below and aptly labelled the 'AGGAT research diamond'.

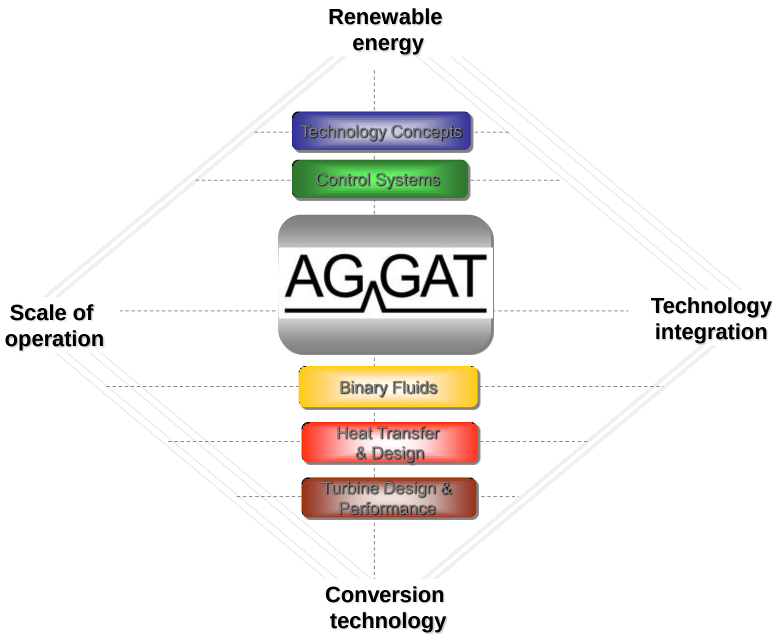



**Figure 2 – The AGGAT research diamond showing the arrangement of relationships between research requisites placed on the diamond corners and the 5 research themes placed in its center**

## 3. AGGAT RESEARCH ROADMAP

Each of the afore-mentioned research themes is now broken down into areas of research interest. It should be noted that these are colour-coded to indicate their priority in the research timeline (green-active, blue-next step, red-long term).

### 3.1 Technological concepts

The theme of technological concepts broadly covers process innovations at a macro-level. Key areas of interest identified under technology concepts are displayed in its research framework as presented in Fig. 3.

#### 3.1.1 Cycle / plant performance

The foremost interest is in how the plant or process performs under given operating conditions. Some of the key metrics identified to measure performance are monitoring of plant efficiency, the balance of power output versus the parasitic load consumed in running motors and pumps, the economics of the overall system and the ambient temperature available as this will have a direct impact on the plant performance. This acknowledges the requisite of cycle/engine or conversion technology in the AGGAT research diamond.

#### 3.1.2 System modelling

System modelling is included to recognize the importance of process simulation and its ability to provide preliminary performance results as well as generate understanding of process dynamics based on performance mapping capabilities developed from analyzing experimental results. A number of software modelling options are available to process and mechanical engineers some of which are currently being utilized as resources within our programme. Finite Element Analysis (FEA) tools in ABAQUS and fluid dynamic simulation techniques in ANSYS have been valuable for process equipment behavior and fluid flow behavior respectively. VMG-Sim is a process modelling software that is currently being used within our research capabilities to develop control system models for ORC plants.

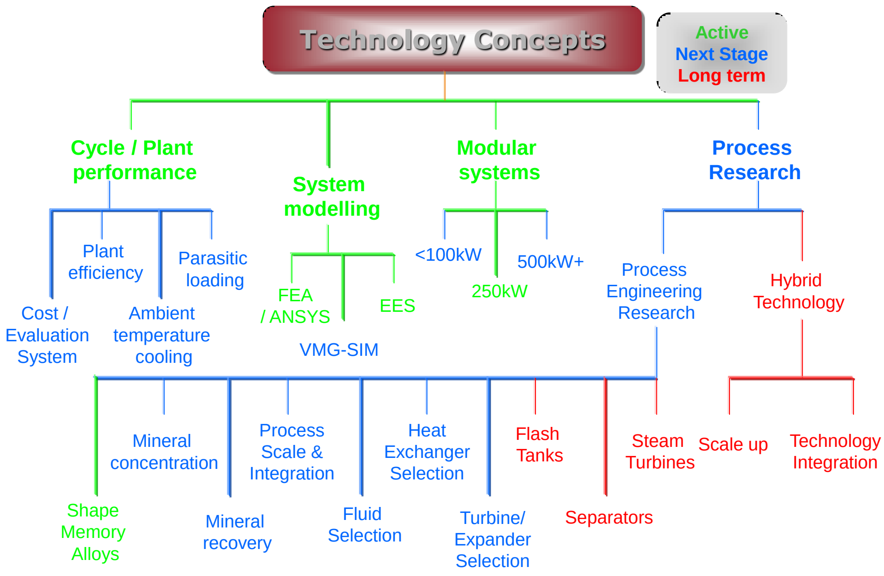



**Figure 3 – Research framework for 'Technology Concepts'**

3.1.3. Modular systems

Deciding on the scale at which the power generation module should be tested also needs definitions. This requirement is identified under modular systems and acknowledges the requisite of 'scale of operation' identified earlier.

3.1.4 Process research

At a macro-level, this research area encapsulates investigations on unit operations under process engineering research and marrying these in hybrid combinations with each other. One of these efforts is to marry above-ground process technologies with below-ground research initiatives such as mineral concentration and recovery. A current investigation is on shape memory alloys and the ability to derive power generation from their temperature dependent shape changing properties.

As mentioned earlier, in the long term, synergies could potentially exist between low enthalpy based technologies such as ORC and conventional high temperature power generation processes utilizing steam. Potentially applicable process innovations could bear synergies for high temperature applications such as flash tanks, separators and steam turbines which have also been included in this process research scope. The requisite of process scale and technology integration as identified earlier is acknowledged under process research.

### 3.2 Turbine Design & Performance

New Zealand heavy engineering companies have a very capable background in turbine repair and manufacture which significantly adds to the local capability set in support of Turbine R&D. The research needs identified under this research theme span its design and engineering requirements. Whilst this could arguably be considered an ambitious undertaking, every effort is being made in the programme to abstain from colloquially speaking 're-inventing the wheel'. The technological achievements of established turbine manufacturers are duly acknowledged and it must be stated that the driver for turbine R&D is to advance the collaborative efforts in turbine performance enhancement at a global scale. A strategic objective in this context is to inform about AGGAT activities on a global platform and open this area for international collaboration. The research interests identified below are potential areas for collaboration opportunities for which the framework is presented in Fig. 4.

3.2.1 Performance

The metrics sought after to monitor turbine performance are its efficiency, life cycle analysis and performance under different operating conditions to gather information on turbine operational boundaries in terms of process conditions, turbine specifications and binary fluid used.

3.2.2 Construction

The breakdown listed under *construction* in Fig. 4 is not exhaustive. The type of turbine (inflow/ outflow/ radial/ axial/ reaction/ impulse) is the primary component defining different types of turbine constructions. Common turbine parts are also listed each of which will have an important contribution towards the overall turbine behavior. These include geometries for blade, nozzles, vanes, rotors and bearings. A similar breakdown has been prepared for expanders but is not included in this paper.

3.2.3 FEA modelling

FEA modelling is necessary to build capability in turbine structural design and its simulation under different environmental loading conditions. In addition, using multi-physics analysis in ABAQUS (well-known FEA modelling software), a reasonable level of fluid dynamic interaction and impact on turbine simulation can also be obtained.

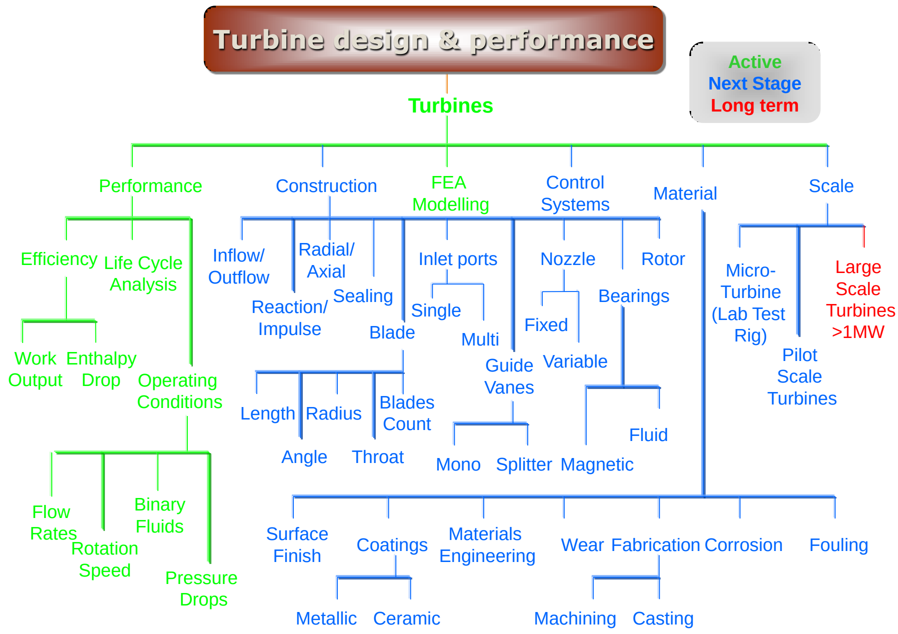



**Figure 4 – Research framework for 'Turbine Design and Performance'**

3.2.4 Control systems

Turbines need control strategies to maintain stability in fluid expansion conditions as well as to modify its operating situation under different loading conditions. Therefore the control strategies commonly applied to turbines will need to be considered as an essential part of turbine R&D. This will also be inter-linked with the research theme of control systems.

3.2.5 Material

Material selection and performance is integral to turbine R&D due to its impact on turbine life-cycle and efficiency. This will require material studies on material type, surface finish and behavior under different operating conditions and with different fluids.

3.2.6 Scale

The scale of turbine operation will be closely related to turbine performance so the metrics used will be the same however subjected to different scales of operation. This will be stretched right through from lab-based (<20kW) to industrial-scale turbines (>100kW – MWs).

### 3.3 Heat Transfer & Design

Many of the requirements for Heat Transfer and Design R&D are similar to Turbine research. The distinction arises due to the relatively different unit operations being carried out by each. A breakdown of research framework for heat transfer and design is provided in Fig. 5.

3.3.1 Type

Due to the well-researched and well-industrialized status of heat exchangers, a lot of information is currently available that is to be built into a database of heat exchangers to inform heat exchanger selection and design processes within the framework of AGGAT activities. Therefore the foremost classifier in heat exchanger research is its type which will then lead the way into asking subsequent research questions governing heat transfer research. Of relevance to AGGAT due to popularity in power plants are the shell and tube heat exchanger (STHE), plate heat exchanger (PHE) and condensers. The list can be expanded to accommodate heat exchange modes (gas/liquid) and will no doubt also be a factor for consideration during site resource analyses.

3.3.2 Performance

Similar benchmarks of efficiency and operating conditions as for turbines are used for heat exchanger performance as well. However, added to this are the standard heat exchanger metrics governing heat transfer measurement such as heat exchanger coefficients and temperature of approach.

3.3.3 ANSYS/EES modelling

Heat transfer can be well-modelled using ANSYS and EES software. These are currently being used in our research programme to simulate behaviours of PHE and finned tube heat exchangers (FTHE) as well as STHEs for given input conditions obtained from selected field-based heat resources.

3.3.4 Control systems

Heat exchangers require control loops for temperature as well as pressure drop maintenance. Understanding these is integral to maximizing efficient heat exchanger performance and this is closely interlinked with the research theme of control systems.

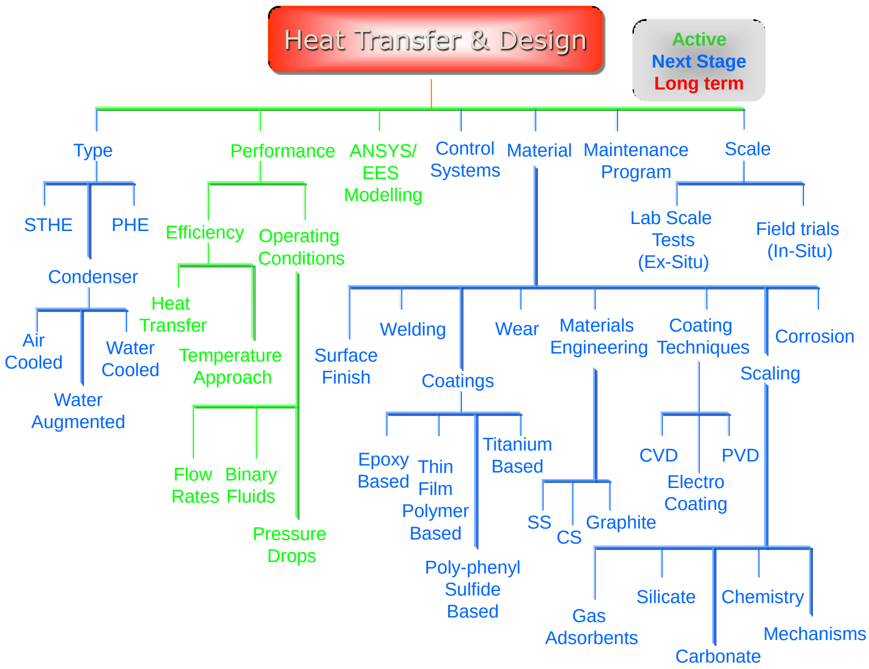



**Figure 5 - Research framework for 'Heat Transfer and Design'**

3.3.5 Material

The material of construction for heat exchangers and its treatment is directly linked to the performance of the heat exchanger under different conditions of corrosion, scaling and fouling. A number of pre-selected surface coatings, coating techniques as well as surface finishing techniques are considered. Alongside, the mechanisms of scaling and corrosion that damage the heat transfer surfaces are also under consideration. Selecting the right material and subjecting it to treatment processes which will best prepare it for handling field-based environments is critical for heat transfer research.

3.3.6 Maintenance program

Currently, in an industrial context, standard heat exchanger maintenance programmes utilize duplex processing lines whereby one heat exchanger can be taken 'off-line' for cleaning. Other maintenance programmes conduct heat exchanger cleaning in place (CIP) which is a common occurrence in the dairy industry due to the relatively higher fouling demand of milk requiring higher CIP frequencies. Determining the right maintenance programme for heat exchangers as well as potentially devising new and innovative maintenance programmes is a relevant consideration from an industry perspective.

3.3.7 Scale

The scale of operation will affect the performance of heat exchangers. For this reason, tests conducted in lab scale trials will have to be re-tested in field-based environments and vice-versa for repeatability.

### 3.4 Binary Fluids

Binary fluids, generally hydrocarbon based liquids are used in ORC processes to transfer energy from primary heat source into the process for conversion to electricity. Binary fluid research is closely interlinked with heat transfer as well as turbines due to its intimate use in both for their unit operations i.e. heat transfer and fluid expansion. Its research framework is given in Fig. 6.

3.4.1 Type

The type of binary fluid is a critical requirement for power generation processes as it will dictate the operating temperature and pressure for the process (based on the fluid thermo-physical properties). The type of fluid used will also determine the nature of operation. For example, the Kalina cycle uses a zeotropic fluid mixture of water and ammonia giving it a temperature-matching advantage and allowing it to operate within a range of boiling temperatures. The binary fluid can be chemically engineered to yield the desired fluid properties. These issues make the type of fluid choice an essential consideration.

3.4.2 Performance

The performance of the binary fluid can be measured using the metrics of efficiency and expansion ratio on the binary fluid based on its performance in the turbine, heat exchanger and the overall cycle. Monitoring the performance of binary fluids will assist in selection of the appropriate fluid when presented with similar heat resource situations. Whilst this could also be achieved through data-mining in literature, it may not always guarantee the expected outcome. This can only be confirmed through experimental verifications which will also be considered for binary fluid research alongside material selection research for heat exchanger and turbines.

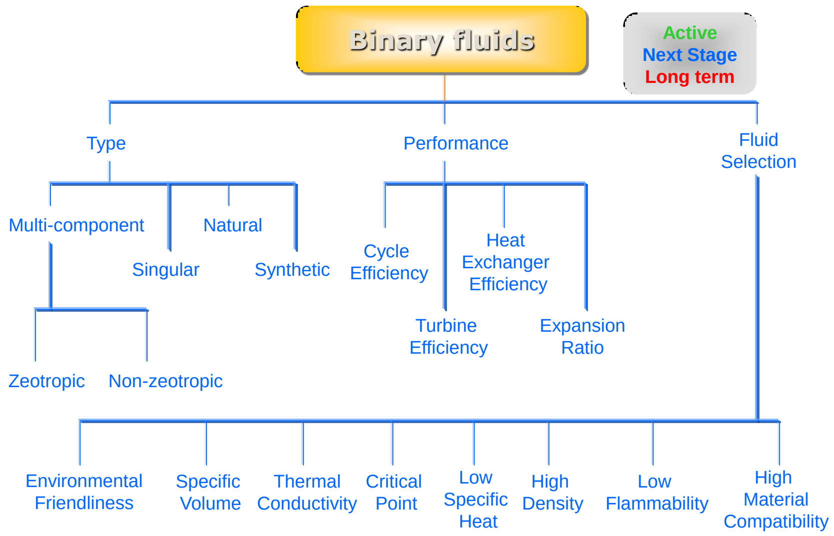



**Figure 6 – Research framework for 'Binary Fluids'**

<u>3.4.3 Fluid selection</u>

The criteria for fluid selection have been presented in literature before by Papadopoulos et al., (2010). This has been adopted for the purpose of fluid selection in our programme and will be amalgamated with other information collected for heat exchanger and turbine performance in the form of a database.

### 3.5 Control Systems

The research theme of control systems provides the roadmap for control strategies and their applications testing for above-ground technologies. Its research framework is provided in Fig. 7.

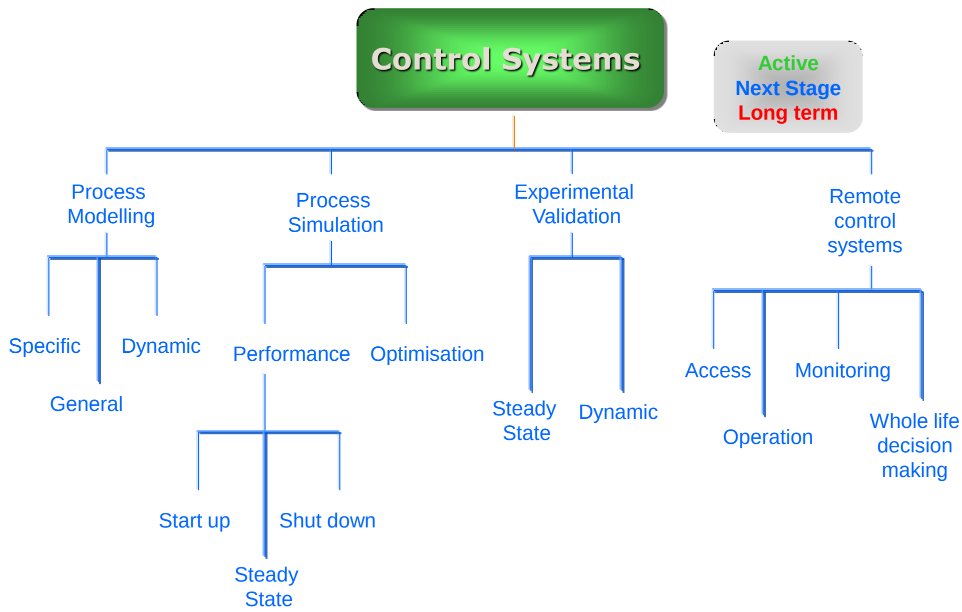



**Figure 7 – Research framework for 'Control Systems'**

<u>3.5.1 Process modelling</u>

The intention under this research interest is to provide a model coded for generic thermodynamic cycles, modify it for dynamic situations and finally tailored for specific process modules.

<u>3.5.2 Process simulation</u>

This research focus is to validate the models developed earlier to confirm model behavior under different simulation environments. Under process simulation, optimization and application of various control strategies (cascade, feed-forward, model-predictive) will also be considered.

3.5.3 Experimental validation

The models created and simulated for their performance will be tested against real data obtained through the embedding of these control systems into real processes and the response curves generated.

3.5.4 Remote control systems

A final aspect for consideration under control systems is the ability to gain remote access for monitoring and potentially controlling purposes dependent on the nature of process in question.

The research frameworks have been formulated into specific research questions which provide the roadmap for AGGAT research. These can be found in the HERA document by Habib et al (2012). Some of these research questions are listed below to provide an understanding of the nature of work packages they entail and provide direction towards progressing in the said research theme.

- *Technology concepts*: Which are the most effective plant set ups / designs to achieve maximum thermodynamic efficiency and power output and minimize energy losses?

- *Turbine design and performance*: Will a bladed turbine perform better than a bladeless expander? Under what circumstances will this be possible and under which it will change?

- *Heat transfer and design*: What kind of materials and alloys can be engineered to improve durability of heat exchangers, reduce scaling and improve heat transfer?

- *Binary fluids*: What is the interaction between binary fluid flow characteristics and erosion, corrosion and scaling phenomena?

- *Control systems*: Can a generic control system be applicable across different waste heat resources and ORC module sizes?

The research roadmap is a live document and has been reviewed extensively across New Zealand by industry and research institutions for input and value-add.

## 4. PROGRAMME MANAGEMENT

### 4.1 Set up

The research document forms the basis for the AGGAT research programme which was formally launched in 2012. The programme adopted two major Impact Statements (IS) i.e. Knowledge Base and Advanced Systems. The first impact statement is a collection of six research aims:

- IS1-1 Expert Design Tool: This research aim is a receptacle for all the information and knowledge gained in the other research aims IS1-2 to IS1-6 and for providing organized solutions for power generation processes at given heat resource input conditions.
- IS1-2 Materials Knowledge Base: This research aim is focused on developing understanding in materials performance for application in heat transfer and fluid expansion processes.
- IS1-3 Scaling Mechanisms: Understanding scaling phenomena taking place in a geothermal environment are the focus of this research aim using numerical modelling techniques
- IS1-4 Heat Transfer Data: The information and understanding of heat transfer performance for given heat transfer conditions are being assimilated in this research aim.
- IS1-5 Expander Research: In this research aim, the objective is to develop understanding of turbo-expanders behavior of different designs and configurations.
- IS1-6 Controls Research: In this research aim, the objective is to build control models and test them for application in generic, dynamic and specific process configurations.

The second impact statement is a collection of four research aims which encapsulate the ‘practical aspect’ of the AGGAT programme through application of the knowledge base into manufacture of advanced systems and products:

- IS2-1 Systems and Modules: This research aim is a collection of all the manufactured products in the other research aims IS2-2 to IS2-4 and their organized assembly into systems and process modules for demonstration of successfully operating power generating facilities.
- IS2-2 Heat Exchanger Concepts: In this research aim, heat exchangers of innovative design are being developed that contribute towards enhanced heat transfer and performance based on understanding developed in IS104.
- IS2-3 Turbo-machinery Development: In this research aim, the objective is to build new turbine designs prepared in IS1-5.
- IS2-4 Control Systems Development: In this research aim, the objective is to test control systems in processing environments for real-time performance of control logics developed in IS1-6.

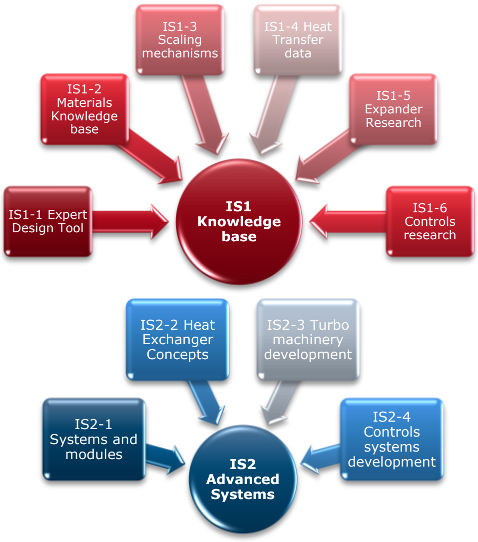
The impact statements, research aims along with their correlation to research themes and research areas given earlier are shown schematically in Fig. 8.

The research programme is now in its second year of activity. However the ground work for this has been laid for at least 3-4 years before that. The drivers for this development are:

- Advancement of above-ground technologies research agenda
- Development of NZ Heavy Engineering manufacturing capability
- Support for the global energy market demand by providing unique solution offerings

Accompanying strategies that are being adopted are:

- Increase in awareness of the AGGAT research roadmap and activities
- Gain in global traction in above ground technologies research
- Synergizing efforts with international achievements to overcome 're-inventing the wheel' phenomenon




| Research Theme | Research Aim | Research Areas |
|---|---|---|
| Technology Concepts | IS1-1, IS2-1 | Cycles, Design Tools, Materials, Modules |
| Heat Transfer & Design | IS1-2, IS1-3, IS1-4, IS2-2 | Heat transfer, Materials, Fluids |
| Turbine design & Performance | IS1-5, IS2-3 | Turbines, Materials, Fluids |
| Control Systems | IS1-6, IS2-4 | Control Systems, Cycles |
| Binary Fluids | IS1-3, IS1-5 | Fluids, Materials |

**Figure 8 – Schematic representation of the AGGAT Programme set up and the correlation of research aims with corresponding research themes.**

This is a unique and challenging programme and as far as the author understands, it is the first of its kind in the world addressing clean energy concerns through R&D initiatives in low enthalpy power generation. Much progress has been made to date. Many challenges have been overcome and many still remain. The challenge of translating research objectives into engineering outcomes is very real with the reality of managing a programme of such scale and ambition presenting itself in the form of many practical issues. Some of the key achievements and accompanying challenges are outlined below:

### 4.2 Achievements, activities and challenges

4.2.1 Establishment and growth of the AGGAT team

Since the inception of these efforts, progress has been made in building of a research and development team comprising of distinguished research engineering experts from notable NZ universities as well as capable industry partners who are committed to the AGGAT vision. The research team now consists of at least 23 active research staff and engineering personnel from at least three active companies based in the Waikato and Bay of Plenty regions of the North Island. In addition, at least nine expressions of strong interest have been received through industry engagement briefings conducted by HERA across New Zealand.

4.2.2 Resource assessments

Five low enthalpy resource sites (two geothermal and three waste heat) have been identified in NZ and resource characterization studies conducted on them. Negotiations are at various stages with the owners of these and other resources. A Memorandum of Understanding has been signed with two of the owners for installation of plants on their sites. Aligning the AGGAT Vision with the business strategies of resource owners is a constant challenge however more are now favorably viewing the long-term benefits of R&D investment in their businesses.

4.2.3 New project concepts

Project concepts for the upcoming companies are being considered that will have interest and relevance for the participating companies. Currently there are four projects that are at various levels of development. One of these is looking at the installation of a 100kW ORC plant at a gas engine resource facility for which process design and resource assessment has been completed. A second project is looking at the potential of testing a boundary layer turbine at lab scale to compare under similar operating conditions with other expanders.

A third project has been generated which is looking at the concept of achieving trigeneration from Stirling cycle technology in a dairy farm environment. The sequential implementation of this approach is schematically represented in Fig. 9. Significant research expertise exists within the AGGAT team in Stirling cycle research. Recently Tucker et al., (2011) published an interesting article explaining the issues surrounding cycle reversibility and net gain in work output. Potential application of this promising technology is an exciting opportunity. A fourth project is looking at investigating the feasibility of using a steam driven positive displacement rotary expander with an organic fluid in a lab scale ORC test rig. Turbine design and development is a major challenge for which such attempts are being carried out to address this challenge.

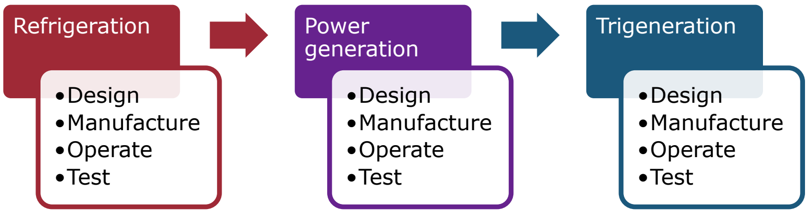



**Figure 9 – Implementation sequence for trigeneration model using Stirling cycle technology**

4.2.4 Field based materials testing opportunity

A negotiation with one of the power companies utilizing geothermal energy in the Taupo Volcanic Zone (TVZ) has progressed successfully to the stage of being given access to their geothermal brine for experimental purposes. The objective is to develop a field based materials testing facility for testing of materials via a purpose-designed and built shell and tube heat exchanger in a geothermal based scaling environment with specific focus on silica scaling. A PID schematic of the process set up is given in Fig. 10, Heinzel, (2014), which shows the STHE (pipe test rig) inline installation. The design and installation process is expected to be completed soon with materials testing beginning in 2014.

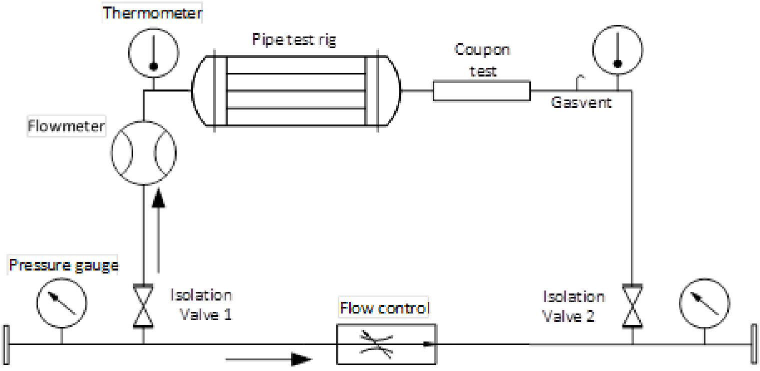



**Figure 10 – A Process and Instrumentation Diagram (PID) of the materials testing facility utilizing geothermal brine. Heinzel, (2014)**

4.2.5 AGGAT events

As a strategic approach to increase awareness of above ground research and to gain greater traction on the work regular events in the forms of workshops have been held in the past two years. An AGGAT workshop was held in 2012 with attendance from both industry and academia. A follow-on AGGAT Summit was arranged in 2013 with increased attendance and new industry participants. The purpose of both these events was to update on AGGAT R&D activities and gain industry feedback. An AGGAT seminar series is taking place mid-2014 which will have a stronger industry focus updating on industry participation and opportunities in clean energy markets for heavy engineering companies. An AGGAT global conference is to be organized in April 2015 as follow-on from the World Geothermal Congress (WGC) taking place in Australia. This will provide a forum to exchange progress notes on AGGAT activities and also open up opportunities for collaboration. Further details of this conference will be available from the HERA website. Other media routes for its promotion are also being arranged.

4.2.6 Literature and market reviews

Regular attempts have been actively made to keep abreast of developing literature and patents in the area of low enthalpy power generation. A state of the art literature review was conducted by HyungChul, (2012) listing the status of development in ORC technology. A subsequent review on patents in energy conversion technologies was conducted by Pauko (2012), which reported on patent developments through researching major patent sites including US, European and World patent resources.

Comprehensive market reviews have been conducted by Ludewig, (2013) for the US and European markets related to ORC plants which were then used to develop business models for them. A related branding study was carried out by Kotouc, (2013) which further developed the market pathways by preparing brand promotion options for engineering companies. These market assessment reports have been valuable in understanding marketing dynamics and staying informed on market environments and activities.

4.2.7 Lab scale ORC rig

A lab scale ORC testing rig has been developed at the Mechanical Engineering department of one of our research partners, the University of Canterbury. This rig is capable of producing up to 1kW of electrical power using waste heat from the exhaust of a Capstone gas turbine.

4.2.8 Control systems modelling

A control systems model has been prepared by our research team members at the Chemical and Materials Engineering department in the University of Auckland. A paper was recently presented on steady state and dynamic ORC modeling states by Proctor, (2013).

## 6. CONCLUSIONS

The AGGAT programme is believed to be the first national scale programme of its kind in the world with the objective of driving industry growth and research innovation forward in low enthalpy power generation. Through the AGGAT research roadmap, key research themes were identified for which research questions have been formulated to direct research efforts in a concerted form. The AGGAT programme is currently working on developing a knowledge base and manufacture of energy conversion technology products based on the understandings developed from the AGGAT knowledge and science base.

Significant industry interest and research progress has been generated to date in the AGGAT programme. However current challenges exist in the form of stakeholder priorities and turbine design. In order to keep pace with international progress, international collaboration opportunities exist within the AGGAT programme and need to be availed for application of existing technologies to industrial situations. A global AGGAT conference is being organized in NZ following the WGC in 2015 which will also provide a forum to update further on AGGAT activities.

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