Case Study August 2025

Under the Strategic Science Investment Fund

Advanced Energy Technology Programme

“High Power electric motor for large-scale Transport”

Capability building – pioneering the advancement of cryogenic power electronics

Fit and motivation for our research programme – Unlocking lighter, smaller power electronics systems for applications important to New Zealand

Power electronic devices at cryogenic temperatures refers to the mechanism, operation, and design of power semiconductors and related components and circuits at cryogenic temperatures, typically below 77 K, the boiling point of liquid nitrogen. They are an emerging and exciting new field of research.

Future long-range, zero-emission electric aircraft will likely use cryogenic fuels (such as liquid hydrogen) and require lightweight, high-efficiency electric motors (such as high-temperature superconducting motors). This large cryogenic reservoir offers the opportunity to operate, develop and optimize power electronic devices at cryogenic temperatures. Operating power electronic systems at cryogenic temperatures could significantly reduce their size and weight - an important advantage for aviation. Similarly, space vehicles and satellites already operate in cold environments and minimizing mass is paramount. Furthermore, there are plans to develop high-power electric ferries or cargo vessels using cryogenic liquefied fuels or onboard energy storage, which would enable more compact power electronic systems.

Beyond this, our programme will support and tap into other related and emerging applications such as future high-efficiency space propulsion, future power grids, large-scale data centres[1], and quantum computing. They all require, or could potentially benefit from, efficient and small power systems operating at cryogenic temperatures.

However, the technology is in its infancy worldwide. More importantly, while New Zealand has strong capabilities in superconducting technologies[2], space applications[3], future grid[4], and quantum technologies[5], we have lacked domestic expertise in this niche but high-potential field.

Therefore, as part of our programme, one of our four workstreams focuses on exploring, developing, and optimising power electronic systems and components for operation at cryogenic temperatures. It is based on, and expands, our world-class expertise and strengthens our standing and partnerships with national and international collaborators in power electronics and cryogenic systems.

Our programme is the first time New Zealand has hosted a dedicated, multi-institutional, cross-disciplinary research programme in cryoelectronics. It has brought together expertise from electrical engineering, materials science, thermal physics, and aerospace systems, involving:

- University of Auckland: Power electronics modelling, packaging, and system integration
- University of Canterbury and former Callaghan Innovation experts: Semiconductor device physics, control systems, cryogenic engineering and thermal-fluid modelling
- University of Cambridge (UK): Next generation materials and systems for power electronic devices
- Victoria University of Wellington (Robinson Research Institute): Superconducting materials and cryogenic thermal design

Our transdisciplinary collaboration has not only delivered key technical outputs but is beginning to position New Zealand as a thought leader in this field and related areas.

Problem – Exploratory device and systems research tackling overheating, unexpected failures, and materials engineering and integration challenges

Currently, efforts to drive power electronic devices at cryogenic temperatures and reduce weight and size often lead to design trade-offs that make thermal management difficult[6]. An additional challenge is managing the extremely high-power levels needed to drive megawatt-class high-temperature superconducting (HTS) motors. While existing power electronics can achieve efficiencies of 98–99% the risk of overheating or sudden failure in semiconductor devices is particularly significant at these power levels.

Leading key research questions are:

- How can we incorporate power electronics devices into the existing cryogenic cooling system to improve efficiency, size and weight and dissipate heat?
- How do we optimize the power electronics packaging and interconnects to minimize size and losses?
- Is it possible to reduce the size of the inductors and capacitors used in the power electronics system at cryogenic temperatures?

Therefore, we focused our research on:

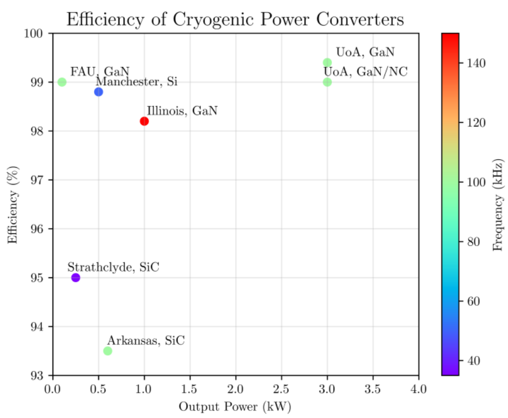
- Understanding and optimizing the behaviour of wide bandgap semiconductors (e.g., silicon carbide and gallium nitride) at cryogenic temperatures
- Designing, building, and testing cryogenically operable power converters
- Developing a custom test infrastructure for extreme low-temperature environments

Key Results - foundation for long-term national capability and strategic resilience.

Over the last 5 years, the power electronics workstream of our programme has delivered multiple key outputs:

- Wide bandgap world record power converter in terms of output power and efficiency at cryogenic temperatures (see Figure below)
- Demonstration of a wide bandgap power electronics motor driver powering a superconducting homopolar motor (see Figure below)
- Development of novel nanocrystalline inductor cores enabling size and weight reduction of 98% at cryogenic temperatures[7].
- Device and material characterisation and optimization of existing SiC and next-generation GaN wide bandgap power devices, including contact optimization and commercial SiC MOSFET and GaN HEMT testing. The latter devices show significantly increased breakdown voltages, and significantly reduced on-resistance and leakage currents, at cryogenic temperatures[8].
- Establishment of cryogenic power electronics test facilities at the Universities of Auckland and Canterbury
- Training of 1 Postdoctoral researcher and 8 PhD students in cryogenic power electronics so far. Some of them have already finished their degree and continue to work in the field or have transitioned to related NZ industry partners.

With the devices and converters now proven functional, the next logical step is to further optimize our cryoelectronics approach while in parallel starting to integrate them with superconducting motors and cryogenic energy storage. This will enable us to demonstrate a fully integrated system for aerospace or marine use.



Left: Output power versus efficiency and switching frequency for power converters at cryogenic temperature. Converters developed at UoA-University of Auckland demonstrate (FAU- Florida Atlantic University, rest - locations at the respective universities). Right: team members and homopolar motor testing at Robinson Research Institute powered by our own 100 kW motor drive developed at the University of Auckland.

From Capability to Impact: enabling new industry and research partnerships

The know-how and infrastructure developed through our programme are now driving innovation and contributing towards whole motor system development.

This is beginning to attract strong interest from international collaborators and major industry partners.

Besides supporting aircraft motor tests at the Air New Zealand test cell in Auckland we held several in-depth meetings with NZ industry (Wellington Drives, Apple) and key international collaborators such as Airbus to explore potential collaborations and research topics.

Top international researchers from USA (Prof. Alan Mantooth, Germany (Prof. Nejila Parspour), UK (Prof. Pat Wheeler) and Japan (Prof. Hiroshi Fujimoto) visited us and two externally funded students from our German partners Fraunhofer IMS and Bosch joined us for several months of research in our laboratories.

These initiatives are the first stepping stones on our journey, delivering tangible outcomes and ultimately impact for Aotearoa/New Zealand by:

- Creating an NZ Inc. niche of research and commercial leadership
- Enabling participation in billion-dollar emerging and future markets
- Supporting decarbonisation and next-generation infrastructure
- Building scientific resilience and sovereign technology capability

For more information about our programme, please visit electrictransport.co.nz

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