MINISTRY OF BUSINESS, INNOVATION & EMPLOYMENT
HĪKINA WHAKATUTUKI

2022 Endeavour Round Successful Projects

SUCCESSFUL 2022 SMART IDEAS

Organisation	Title	Science Leader(s)	Duration *(years)*	Contract Value *(GST excl)*	Applicant's Public Statement
AgResearch Limited	Machine learning and CRISPR technologies to understand rumen methanogen interactions	Dr Sandeep Gupta	3	$999,999	Methane produced by farmed animals is a major source of greenhouse gas and a leading contributor to global warming from human activity. In Aotearoa NZ, methane produced by farmed animals accounts for 86% of all greenhouse gas production from the agriculture sector. Methanogens that live in the rumen (stomach) of the livestock are responsible for methane production but are also vital to the animals' digestion and nutrition. The development of a vaccine and/or chemical inhibitors to mitigate this methane production by methanogens in livestock is now a primary objective for scientists, industry, and the government in Aotearoa NZ. But lack of knowledge about the methanogen genes that are involved in methane production has hindered development of these tools. We will combine Machine Learning algorithms and CRISPR gene-editing technologies to identify the genes of rumen methanogens that are responsible for methane production. We will develop new Machine Learning algorithms to predict gene function in the rumen methanogens and develop a new way to deliver gene editing technology into methanogens in order to study the function of any key genes of interest. This information will provide much needed scientific knowledge on a novel set of effective vaccine or chemical inhibitor targets to mitigate methane production by rumen methanogens, thereby reducing methane emissions in ruminant animals such as cows and sheep. Collectively, these approaches will help in developing effective strategies to reduce methane emissions from ruminant livestock, enabling Aotearoa NZ to meet its greenhouse gas emissions targets, ensuring the agriculture sector retains social and environmental licence-to-operate and improving sustainable animal production in Aotearoa NZ.
Auckland University of Technology	Tunable and stimuli-responsive cellulose-based surfactants – from emulsifiers to defoamers	Mr Jack Chen	3	$999,972	Emulsification is an integral part of industrial processes but can become an expensive liability. The surfactants added to stabilise emulsions also cause foaming. Excessive foaming artificially raises the batch volume and can result in product loss, damage to equipment, factory downtime and environmental pollution. Entrapped air from foam that remains in the finished product can cause clouding, voids and compromise the structural integrity of the product. Companies deal with these problems by spending an estimated US $3 billion a year on chemical additives called defoamers. Apart from their high cost, defoamers can contaminate the final product and are often considered environmental pollutants. We propose an entirely new class of surfactants where the emulsification/foaming properties can be switched on and off on demand. This technology would be particularly useful in cases where emulsification is important in one part of a manufacturing process but becomes problematic further along the process when emulsification and foaming are undesired. Examples include froth flotation apparatus that are in the pulp and paper industry for recycling, in wastewater treatment and in numerous industries for cleaning of the effluent before discharge. The ability to control when emulsions are formed will enhance the efficiency and cost-effectiveness of manufacturing processes and reduce the production of contaminated effluent. Utilising cellulose as a feedstock also provides a unique opportunity to turn low-value products, and waste from our primary industry into a value-added commodity.
Barenburg New Zealand Limited	Preferred intake ryegrass for livestock gain and pasture resilience	Colin Eady	3	$999,999	Barenbrug has identified an unusual distantly related ryegrass ecotype that exhibits a unique property that may improve livestock gain efficiency and pasture resilience. Over the past 16 years, this character has been bred into elite New Zealand germplasm resulting in plant lines with known genetic structure and a diverse range of this trait in the field. Using state-of-the-art metabolomic and genomic tools, the aim of this project is to identify the chemicals and genetic tags responsible for this character. This knowledge will facilitate the breeding of ryegrass cultivars that will substantially improve livestock gain through improved pasture utilisation. Improved ryegrass utilization will help maintain legumes, herb species, and other more resilient grasses in mixed pastures. The anticipated outcomes include promotion of biological nitrogen fixation, mitigation against nitrogen leaching, and improved management and maintenance of diverse, resilient, productive pastures in alignment with regenerative farming goals.
Bodeker Scientific Limited	Using artificial intelligence to improve weather forecasts	Greg Bodeker	2	$999,880	Bad weather can be far more than just an inconvenience. In NZ, where primary production contributes $22.5B to our economy, bad weather can incur significant economic, environmental and social costs. Mitigating the impacts of severe weather largely depends on the quality and reliability of weather forecasts. The most highly damaging extreme weather events (e.g. hail or intense rainfall) often occur over small areas, driving a need for higher-spatial-resolution forecasts. By solving the mathematical equations describing atmospheric processes, numerical weather prediction (NWP) models predict how the weather will change - this computationally demanding task requires supercomputers. Increasing the model resolution, so that they resolve local weather events, adds large financial costs. We will apply artificial intelligence methods to develop a new way of generating weather forecasts, producing high-resolution forecasts at a fraction of current costs. A neural network (NN) will be trained to learn how to generate weather at hyperlocal scales (several 100m) given data from a lower resolution NWP model. While the initial training may be computationally expensive, once trained, the NN can be applied to any NWP forecast to fill in the missing detail inside each grid-cell, at negligible cost. This cost reduction means that we can generate higher resolution forecasts than are currently available, and process many more forecasts to produce probabilistic risk assessments of rare but highly damaging events. If successful, our fused-NN-NWP model will be incorporated into MetService's NWP chain, delivering new hyperlocal weather forecasts, enhancing the ability of emergency managers to save lives and protect property, and industries to manage risks and minimise losses. The need for such forecasts will only increase as the frequency and severity of extreme weather events increase under climate change.

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Cawthron Institute	Transforming coastal monitoring: harnessing microbial communities to disentangle multi-stressor impacts	Dr Dana Clark	3	$1,000,000	Estuaries are dynamic mixing zones between rivers and the ocean supporting some of the most productive ecosystems on Earth. New Zealand has more than 400 estuaries along its coastline, and they are enormously valuable to our economy, environment and society. However, in New Zealand and worldwide, estuary health is declining at an alarming rate. Estuaries face many environmental threats, ranging from pollution to climate change, and these can combine to create catastrophic tipping points from which it is very difficult to recover. Current efforts to protect and restore estuaries are failing because we haven't fully understood how these tipping points are triggered or had monitoring tools that can detect signs of declining estuary health early enough to intervene. In our project, we will examine whether microbes (e.g., bacteria, microscopic algae) can be used to develop tools that transform the way we monitor our estuaries. Microbes underpin estuary health and preliminary studies have shown that they are sensitive enough to detect subtle changes in ecosystem health, enabling early warning of approaching tipping points. Many organisations in New Zealand would like to use these tools. However, the tools alone would not enable the kind of transformation in estuary monitoring that we need. We will develop a world-leading holistic framework for estuary monitoring that combines microbial tools with mātauranga Māori and conventional estuary monitoring data to harness the benefits of each approach. This information will be translated into management actions that will have a significant impact on estuary health. Our project will place Aotearoa New Zealand at the forefront of coastal indicator development worldwide and lead to a step-change in estuary biomonitoring that will enable targeted management before irreversible environmental damage occurs.
Climate Prescience Limited	The Climate Shift Forecaster – Projecting Temperature-Precipitation Space to Ensure a Climate-Resilient Economy	Dr Nathanael Melia	3	$1,000,000	The physical impacts of climate change will continue to affect us all, from shifting extreme weather events to changes in our seasons. However, understanding climate change information remains challenging and restricts an organisation's ability to prepare and adapt to climate change. Traditional climate change assessments can be over 100 pages long, containing maps of average changes to weather variables like temperature and precipitation. We see two disadvantages with this approach: 1. Traditional climate change assessments only help large organisations that already understand their relationship with climate. For example, it is unclear what an average increase of 1°C or 40mm of rainfall means to Kiwi organisations wishing to build resilience, adapt, and thrive in a changing climate. 2. We don't live in an average climate; we experience weather events and an uncertain future; average maps in traditional climate change assessments fail to capture and convey this information. We will develop a new technique to project the seasonal temperature and precipitation cycles to address these issues. These projections will be available via the *Climate Shift Forecaster*, an online platform where users can search their local and global locations of interest and determine their climate shift percentages. Our research will collaborate with leading Aotearoa and UK climate scientists and be stress tested against results from full climate change risk assessments that Climate Prescience routinely produces. To learn more about our research, contact nathanael@climateprescience.com.
GNS Science	Large landslides as ground motion calibrators in the Hikurangi margin	Robert Langridge	3	$999,954	The Hikurangi subduction zone (HSZ) off the eastern North Island is capable of generating magnitude >8 earthquakes resulting in severe impacts for the people, infrastructure, economy, and landscape of Aotearoa-New Zealand. The southern HSZ alone poses a 26% probability of rupture within the next 50 years. However, we have not experienced a 'great' HSZ earthquake for at least two centuries. This means that seismic hazard scientists have very limited data from which to model the effects of 'great' HSZ earthquakes. So, what indicators are out there that can help understand future HSZ shaking scenarios? Large earthquake-induced landslides (LEILs) provide information to unravel the past history of landscape damage. The 2016 M_w 7.8 Kaikōura earthquake provided many important insights for understanding LEILs in Aotearoa-New Zealand that will enable us to distinguish between HSZ-derived landslides and upper-plate fault or weather-derived landslides in the Wairarapa region. Our MBIE Smart Idea brings a novel, proof-of-concept approach to landslide and fault source research. We will create a Wairarapa landslide database using state-of-the-art LiDAR to assess LEIL distributions; undertake geologic studies to date historical (1855, 1942) and pre-historical landslides; and utilise ShakeMaps and probabilistic maps of co-seismic landscape damage to help define the source process. We will work with Rangitāne o Wairarapa iwi to explore mātauranga related to deaths resulting from the notable 1855 earthquake in this area. Results will inform the national seismic hazard model so that informed planning can be made towards natural hazard events. Outreach with existing programs in the Wellington/Wairarapa region (WREMO, It's Our Fault) will allow us to disseminate our results to a wide set of end-users, and importantly the Aotearoa-New Zealand public.

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Landcare Research	Leveraging neuropharmacology to target trap-shy and bait-shy vertebrate pests	Mr Graham Hickling	3	$850,000	Our past research has shown that bait-shy animals continue to feed cautiously on small amounts of non-toxic 'pre-feed' bait. Our Smart Idea is that adding neuropharmacologically active compounds to pre-feed can restore these shy pests' drive to enter traps or consume toxic bait. Vertebrate pest eradication programmes fail, in part, because control efforts usually generate some bait-shy and trap-shy survivors that are wary of subsequent control attempts. These animals quickly breed to restore the previous population. As a result, the Department of Conservation, regional councils and community conservation groups struggle to reduce populations of rats, possums and other pests on the New Zealand mainland. These groups are urgently seeking new tools to improve their pest control success. For possums and ship rats we will use neuropharmacological methods to identify chemical compounds that provide a much greater stimulus to the reward circuitry of these animals' brains than they experience from normal foods or traditional baits. By combining these methods with our understanding of vertebrate pest behaviour, we will: 1. Determine the influence of a range of additives on dopamine release in the brain of possums and ship rats 2. measure the change in bait-seeking behaviour generated by that dopamine release. We will use these steps to identify compounds that can be incorporated into baits to enhance the trappability of ship rats and possums. By increasing target species' drive to seek out and interact with traps and baits – thereby removing pests that were previously difficult to control – our approach will greatly improve the cost-effectiveness of many current pest control methods, including matauranga Maori techniques.
Massey University	Enlisting Kākahi: developing a model system to protect Māui dolphins from toxoplasmosis	Wendi Roe	3	$999,999	*Toxoplasma*, a parasite carried by cats and shed in their faeces, has been identified as a major risk factor threatening the critically endangered Māui dolphin. We have found that one particular strain of this parasite is responsible for Māui and Hector's dolphin deaths, as well as for deaths of native birds. A crucial challenge in managing this risk is to work out when and where the parasite gets into our waterways - there may be specific habitats or cat populations that produce this virulent strain. From these sites, *Toxoplasma* organisms are washed into waterways (rivers and lakes) and ultimately to harbours and estuaries (Māui dolphin feeding grounds). Marine mussels have been shown to concentrate *Toxoplasma* in their haemolymph (the shellfish equivalent of blood), and we believe that kākahi (native freshwater mussels) will do the same, and can be used at a local scale to determine hotspots of *Toxoplasma* waterway contamination. Our study will use molecular methods to test kākahi haemolymph for *Toxoplasma* organisms, and to work out whether the virulent strain is associated with particular cat habitats. Using information on landuse, weather conditions and cat host population, we will get a clearer picture of the parasite's transmission pathways from land to sea, and create a machine learning model that can predict exposure hotspots. The knowledge we gain from this study can be used to target disease management at the most relevant areas, with an ultimate aim of decreasing the amount of *Toxoplasma* entering our waters, and preventing Māui dolphin deaths.
	Kōwhaiwhai pūtoi koiora - Kōwhaiwhai based biomaterial packaging	PUBLISH BOTH: Professor John Bronlund and Robert Jahnke	2	$1,000,000	Kōwhaiwhai is a non-figurative design system, comprised of a series of patterns, aligned with unfurling shoots of the fern frond, the flowering beak-shaped ngutu kākā shrub and the dynamic rhythm of ocean tides. The patterns, inspired by nature, can typically be found painted or carved in meeting houses, storehouses, canoes and paddles. Kōwhaiwhai are not just decorative but impart an important cultural narrative. We have observed similarities between kōwhaiwhai and auxetic patterns. While regular materials thin laterally when stretched, auxetic materials thicken, providing unique functionality such as enhanced shock and vibration energy absorption, and flexibility to stiff materials. These features produce 3D-shapes and properties from 2D-sheeted materials. These new materials can add value and protect foods as innovative food packaging. Exports from the NZ primary sector total around $37b/yr with a growth target of $64b/yr by 2025. Every product uses packaging to protect it from physical damage and spoilage, making packaging one of NZ's major export products by volume. Through an exciting research collaboration between Toioho ki Āpiti (Maori art section, School of Art) and Food Packaging Engineering at Massey University, together with materials expertise from Scion and Callaghan Innovation, we will develop novel packaging applications of kōwhaiwhai that are consistent with its use, while positively promoting and embracing Māori culture. We will associate kōwhaiwhai within contexts consistent with Māori values of kaitiakitanga (guardianship of the land) by adopting biomaterials such as paper and fibreboard instead of plastics. This research will deliver novel science-based methodologies to design kōwhaiwhai-based materials with: • unique and tailored inherent mechanical functionality • the ability to embed an underlying narrative • universally recognisable NZ Aotearoa provenance • made from environmentally sustainable materials • protectable under Trademark and Copyright Acts.

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	Robust volcanic eruption forecasts: leveraging magmatic speedometry into geophysical monitoring	Professor Georg Zellmer	3	$999,972	During volcanic unrest, the main question asked of a volcano monitoring agency is: "When will the volcano erupt?" This question is very difficult to answer, because the interpretation of monitoring signals requires a comprehensive understanding of the magmatic processes that precede an eruption. Recently, we have taken advantage of the extensive record of these processes preserved in deposits from past Tongariro Volcanic Centre eruptions. These deposits contain crystals that indicate magma ascended from depth, taking between two and four days to reach the surface to erupt, i.e., long enough for effective hazard mitigation if magma ascent is associated with clearly detectable geophysical signals. The critical next steps require a link between these ascent rate findings to typical volcano monitoring strategies, namely seismicity and deformation. We will utilise a three-staged approach: (i) study historical (digital and analogue) seismic records prior to previous eruptions to characterise the signals; (ii) forward model volcano deformation using various magma volumes and geometries; and (iii) extend magma ascent analysis to eruptions that produce voluminous lava flows, another hazard in the Central Plateau volcanoes. The goals of our research are: (i) enhance the detection of pre-eruptive magma ascent in real-time seismic monitoring; (ii) compare real-time volcano deformation to a database of simulated deformation models to rapidly identify the geometry of future magma ascent paths and likely eruption sites; and (iii) forecast time-windows between geophysical unrest and eruption for both explosive and effusive eruptions. This work will unfold its transformational impacts during future episodes of volcanic activity, where it will significantly contribute to saving lives, reducing injuries, protecting livestock and infrastructure, and enhancing environmental remediation, thus providing social, economic and environmental benefits to New Zealand.
	Smart Capacitive Sensing Floors for Smarter Homes	Dr Fakhrul Alam	3	$999,991	Imagine a world where your home knows exactly where you are, ascertains that you are going to the fridge for a midnight snack and turns on the night light. Rescue personnel know exactly how many individuals have evacuated a residence during an emergency, and the HVAC system operates more efficiently by sensing who is where. The floor detects a body lying motionless and instantly alerts hospitals and relatives to a fall. The floor tracks an occupants' footsteps, calculates that an occupant's walking pattern has changed and alerts the family doctor to investigate early onset of a disease like Alzheimer's or progressing frailty increasing the risk of suffering a fall. Associate Professor Fakhrul Alam of Massey University is teaming up with scientists and engineers from Scion, Resene, and three other NZ universities to make these scenarios possible. Over the next three years the team will develop an innovative Smart Floor capable of making homes and aged-care facilities safer. The Smart Floor operates by measuring changes in capacitive coupling between the human body and the floor, analogous to how your finger interacts with a touchscreen. Processing the sensed data from the floor using powerful machine learning algorithms allows the data to be used to track movement, interpret body positioning, and even differentiate between people by assigning unique characteristics to each occupant, all in a seamless privacy-maintaining way with no cameras or wearable devices.
	Smart Robotic Capsule to Advance Management of Gastrointestinal Diseases	Ebubekir Avci	3	$1,000,000	Management of gastrointestinal diseases would be revolutionised if, instead of invasive and embarrassing endoscopy and faecal sampling, we could simply swallow a capsule that travelled along the gastrointestinal track taking images and collecting samples at precise locations. In this project, a team of engineers, led by Dr Ebubekir Avci from Massey University, will develop a revolutionary smart robotic capsule that is minimally-invasive, remotely deployable, able to access the entire gastrointestinal track, and collect images/samples of luminal content and gut wall. This technology will advance the management of gastrointestinal diseases by enabling early accurate diagnosis, less-invasive ongoing monitoring of treatment efficacy, and lower rates of complications. World-leading microfabrication and biomedical device instrumentation expertise will combine to develop a fit-for-purpose pill-sized capsule with innovative microactuators and sensors that allow precise positioning and sampling within the gut. The cutting-edge advances in robotics facilitated here have additional exciting applications in the field of small-scale intelligent systems, such as personalised nutrition technologies, environmental remedies, and earthquake search-and-rescue robots. The exciting interdisciplinary team who will make this vision a reality includes engineers, specialist gastrointestinal clinicians, nutrition and gut physiology experts, biomedical device entrepreneurs, and Maori advisors, representing 3 Universities, 1 CRI, a hospital, and private businesses.
National Institute of Water and Atmospheric Research Limited	A coupled climate-catchment-lake mixing model to protect New Zealand's iconic deep lakes	Piet Verburg	3	$1,000,000	This project models the impacts of climate change on lakes, including the effects of climate change on river inflows from the catchment. The focus is on Lake Taupo and the amount of oxygen in its bottom waters. We model the climate up to the year 2100, use that to model the hydrology of the rivers flowing into Lake Taupo, and then model the response in the lake to climate change, using highly detailed 3D lake modelling. We verify the modelling for the present by comparing with observations from lake and river monitoring including the Taupo buoy. We expect that including the climate change effects on the quantity, temperature and density, oxygen content and timing of the inflows from the catchment can provide new insights missing from most research on climate change effects on lakes. We will examine the important question whether climate change, depending on CO2 emission scenarios, will cause bottom water to lose all its oxygen. Changes in vertical mixing during winter and changes in river inflows could result in such a loss of oxygen in the deep water. This would in turn trigger release of phosphorus from the sediments (its concentration in the sediments is high) and potentially lead to eutrophication. The work can provide insights into climate change effects on deep lakes in general, and development of management approaches to mitigate these impacts.

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	Cable bacteria biofilm reactor for low-cost, zero-emissions removal of nitrate from wastewater	Dr Alvin Nugraha Setiawan	3	$1,000,000	Excessive nitrate levels in our waterways is a nationwide problem. It causes environmental degradation to waterways and coastal areas from eutrophication, affecting values we hold dear (economic, cultural, environmental, health, well-being). Widespread concern over nitrate is a major contributor to broader water quality being consistently the top environmental concern for NZ since at least 2010. However, no current technology is available for widespread use in NZ. Conventional technologies to remove nitrate from wastewater are electricity-intensive, utilise non-renewable-carbon sources to feed conventional denitrifying microbes, and unintentionally generate significant GHG emissions (e.g., CO_2, N_2O). Municipal wastewater treatment plants (WWTPs) produce 258 kt of CO_2-e annually (approximately 0.3% of national emissions) and are a key source of N_2O, necessitating emissions reductions in alignment with the Zero Carbon Act. Our proposed research will address the challenge of developing an energy-efficient, net-zero-emission process for wastewater nitrate removal, requiring minimal capital investment to incorporate into existing/future WWTPs and other water denitrification applications. This will be achieved with through a world-first combination of two types of bacteria with synergistic features: one that is able to **denitrify** with **zero CO_2 and minimal N_2O** across a biofilm surface, and another that can boost the denitrification efficiency by effectively creating an additional surface layer. This technology will enable wide implementation of net-zero carbon wastewater denitrification to potentially remove the majority of point-source nitrates; to improve the health of our waterways and the wellbeing of New Zealanders.
	Combining Physics and Artificial Intelligence—A hybrid model for actionable climate projections	Neelesh Rampal	3	$1,000,000	**The Problem** Understanding how New Zealand's climate will continue to change across the 21st century critically depends on sophisticated physics-based climate models. Regional Climate Models are used to enhance the spatial resolution of Global Climate Models, simulate extreme events and enhance the overall relevance for societal decision-making. However, the extreme computational expense of Regional Climate Models presents a major bottleneck for running the required simulations at very high spatial resolution. **Our Solution** To overcome this major scientific challenge, we will construct the first hybrid Regional Climate Model emulator, driven by Artificial Intelligence and informed by physics. This approach will drastically reduce compute times of Regional Climate Models, enabling the first large ensemble (30 models) of very high-resolution (2.2km) nation-wide climate projections. Not previously attempted before, our application of physics-informed AI to regional climate modelling will require significant scientific stretch and involve training petabyte-scale AI models on climate simulations. Despite this challenging goal, preliminary work by our team indicates the potential for a 1000-fold computational speedup compared to current Regional Climate Models. **The Benefits** Our research outputs have the potential to substantially improve decision-making for climate adaptation and support resilience for extreme events. The uptake of this research will also provide substantial benefits to Māori by increasing localized climate resilience and providing opportunities for more strategic investments that enable higher-value products and services.
	Top-down accounting of methane: Protecting farmers from carbon-cost for misattributed wetland methane	Withheld	3	$1,000,000	Methane, an important greenhouse gas, is emitted by livestock as well as wetlands. Livestock industries in Aotearoa-New Zealand will soon be subject to carbon pricing for their greenhouse gas emissions under the Emissions Trading Scheme or equivalent pricing. Methane emissions from nearby wetlands could be wrongly attributed to livestock. This would lead to a competitive disadvantage on the national and international markets. This study will pioneer the use of a chemical marker in atmospheric methane that will allow a clear distinction between methane emitted from wetlands and by livestock. Additional measurements will provide an improved understanding of how large wetland methane fluxes are in various regions of New Zealand and how they vary with time. Our research will inform wetland management and restoration projects that enhance carbon storage and biodiversity in wetlands. In combination, the novel marker and reliable knowledge of wetland dynamics will provide an accurate assessment of the separate livestock and wetland emissions from individual farms to the whole country. Farmers will benefit from fair greenhouse gas accounting for the profitability of their business. Emissions reductions on farms from mitigation technologies will be properly recognised, promoting the uptake and export potential for these technologies. The study will also ensure accurate accounting of national greenhouse gas emissions, which include a major component of agricultural methane. This is a prerequisite to the fulfilment of New Zealand's international obligations to combat climate change.

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	Wai-Spy with an artificial eye: now-casting water quality using real-time camera radiometry	Rebecca Stott	3	$1,000,000	New Zealanders want clear, swimmable freshwaters that are safe for recreational and cultural activities (e.g., waka ama, mahinga kai). However, two-thirds of New Zealand rivers contain pollution above acceptable levels and are often unsuitable for recreation and cultural uses. Current advisory systems rely on historical grading or, at best, 1-7 day-old measurements at a few designated swimming sites so are inadequate in providing timely warnings of poor recreational water quality. This project will develop '**Wai-Spy'**, a cost-effective, real-time warning system for recreational freshwater quality risks. Wai-Spy will use simple camera systems as *in-situ* radiometers to monitor visual clarity and microbial quality at freshwater swimming sites *before* people enter rivers. Wai-Spy will provide hourly estimates throughout the day of visual clarity and *E.coli* concentration – the two health-related variables that most strongly influence freshwater 'swimmability'. Wai-Spy will be locally calibrated and validated in partnership with citizen scientists, including iwi/hapū at selected swimming sites using smartphone cameras alongside cultural and community-based water monitoring methods. Successful delivery of 'now-casts' using Wai-Spy can potentially transform monitoring and management of freshwater swimming sites in New Zealand and internationally. Timely, accessible, location-specific warnings of swimming suitability and health risks will support safer and more rewarding freshwater recreation and cultural uses, and reduce the incidence of illnesses and associated health care costs currently arising from contact recreation when freshwater quality is poor. Partnering with councils and iwi/communities will build local capacity to monitor water quality and ensure local relevance, assisting effective communication of real-time risks and guiding appropriate management responses (e.g., signage, closures/rāhui). In turn, this will inform higher-level freshwater decision-making via iwi and council environmental management plans, promoting kaitiakitanga and strengthening participation in freshwater co-management.
New Zealand Forest Research Institute Limited	Implanted sensors monitoring tree health and carbon capture efficiency	Dr Yi Chen	3	$1,000,000	Forests are hosting significant biodiversity, they are key to climate change mitigation and play an important role in NZ's economy. Traditionally the forest management sector perceives large forestry blocks as uniform entities. Remote sensing uses a new generation of tools (satellites and drones) to monitor forests ecosystem global fluctuations. While very powerful, these techniques can be expensive to implement, require a large dataset to be analysed and often need ground-truthing validation. Precision forestry is an emerging branch of forest management aimed at enhancing the potential of forests and future-proofing their resilience to climate change. To implement this practice new devices able to continuously monitor the physiological processes of individual trees in real-time need to be developed. This work aims at adapting and creating low-cost, implantable bioelectronics sensors able to holistically measure tree's nutritional status, vitality and microbiome fitness. This will be achieved by measuring the concentrations of potassium cations in xylem, sucrose in phloem and under-bark methane. For this, we will use organic electrochemical transistor (OECT) sensor technology. To allow the rapid transfer of information the generated data will be transmitted via a wireless network meshed with Internet of Things (IoT) devices. The data fusion between remote sensing and physiological sensors will allow foresters, and forest managers to quickly implement best management practices. The wealth of data will empower scientists to decipher fundamental aspects of tree biology and use these tools to select the cultivars best suited for future climate change. The implementation of sensors in forests will be also used as an early diagnosis system again pathogens. We also believe that this technology will create opportunities for engaging citizens and forest managers in this new generation of forest monitoring.
	Plant-inspired 3D-printed scaffold for tissue culture	Ms Roya Rezanavaz	3	$900,000	Replicating the microenvironment that cells experience in a natural organism (*in vivo*) is extremely challenging in the laboratory (*in vitro*), yet it is the key to successful tissue culture. Tissue culture (TC) is critical in many disciplines of research, commercial applications and bio-based industries, and therefore improvement of this technique can have a large impact in these sectors. In an intact organism, cells experience complex interactions between cell populations and responses to external signals associated with the variable physical structure as well as a multitude of gradients of different phytohormones and nutrients. To further improve success rates of cell regeneration using TC would require a microenvironment with gradients of stiffness, nutrients and hormones embedded, and 3D tissue structures (scaffolds) in the confined environment to better mimic natural tissue conditions. Over the past few decades, various technologies have been developed to replicate such microenvironment for TC. However, they lack the ability to create an optimised microenvironment for a particular cell type and its developmental stages, especially for recalcitrant species. We propose to develop the technology to produce such a system using an adopted multi-vat 3D printer and test it in the context of *in vitro* plant regeneration via somatic embryogenesis (SE), which is currently being developed to produce trees for the NZ forestry industry.

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The New Zealand Institute for Plant and Food Research Limited	Beekeeping outside the box: developing innovative colony handling and hive architecture	Dr Ashley Mortensen	2	$1,000,000	beekeeping practices were developed to support honey production and have remained relatively unchanged since the advent of the 'modern' beehive in the 1850s. In contrast, there have been tremendous changes during that time in how the crops that honeybees pollinate are managed. This has led to tensions for beekeepers and growers, as beekeepers have to decide if they will dedicate their colonies to honey production or pollination each year. We believe we have discovered a management strategy that will allow beekeepers to retain their large, mature colonies for honey production and still produce specialised pollination colonies. This strategy intends to increase productivity, reduce operating costs, and enable strategic decision-making for beekeepers, leading to increased availability of honeybees for crop pollination. We aim to understand how to initiate and maintain the time point in the honeybee colony's life cycle when they are focused on establishing a new nest. We believe that during this time more worker bees focus on foraging for nectar and pollen rather than other jobs that they may otherwise do inside the hive. Our resulting *'bee'spoke* pollination colonies will be lightweight and allow for better placement of bees in orchards, to further improve pollination of fruits and seeds. We are collaborating with international experts at Texas A&M University, and partnering with iwi and Māori-owned businesses to weave mātauranga Māori and Western science together for results that are accessible and beneficial for all Aotearoa and of interest globally.
	How many flowers? Sugars, hormones and dioecy	Dr Simona Nardozza	3	$999,999	Crop yields rely on flower numbers and quality, and these historically have been shown to vary according to climate. With predicted climate change, this will be exacerbated: flower numbers will be more inconsistent between seasons and current mitigation techniques (e.g. labour and chemicals) will become increasingly unsustainable, making profitable and sustainable crop yields a challenge for growers. Using our unique kiwifruit model system to study flower abortion/retention, we will identify unknown regulators of flower number and corresponding metabolic pathways that could be used to ensure high crop yields. We will develop novel tools to select new cultivars with the desired flower number and yield in kiwifruit, and these could then be translated to other perennial crops, such as avocado, citrus, grape and apple. Our science team includes experts in flower biology, plant signalling and metabolism, including leading scientists from three international labs and local students. Our advisory group will engage with the horticulture industry, including Māori growers, to set the path for future development and uptake of this knowledge.
	Sustainable, intelligent fruit production through novel nozzles for autonomous pollination	Dr Paul Martinsen	3	$1,000,000	Imagine a world without bees. Insect-pollinators contribute to more than one-third of the food we eat, and our dependence on insect-pollinated plants is growing. Meanwhile, wild pollinators are declining, placing strain on managed pollinators to fill the gap. Yet these insect-pollinators face existential threats from disease, over-population and changing climates. We imagine NZ transforming global pollination services, building a diverse agritech export-sector with our research on precision autonomous-pollination providing an intelligent alternative to insect-pollinators. Contact us at Plant and Food Research if you would like to be involved.
University of Auckland	A Multimodal Wearable Device for the Rapid Detection of Complications after Gut Surgery	Assistant Professor Greg O'Grady	3	$1,000,000	Complications are a significant problem for patients and surgeons after major bowel surgery. One of the most feared and deadly complications is anastomotic leak, where a join in the bowel breaks down and starts to leak into the abdomen. Unfortunately, the diagnosis of these complications is often delayed, as doctors have to rely on non-specific signs, symptoms, and blood tests. If leaks and other postoperative complications could be detected early, they could be managed before patients become unwell. We will develop a wearable device to detect anastomotic leaks and other postoperative complications, combining multiple sensor technologies to help monitor patients more closely after surgery. We will design this device together with patients, surgeons, nurses, and other healthcare workers to ensure it can be easily applied in hospitals. Input from Māori will ensure the device is culturally safe, especially given that Māori patients have a greater burden from postoperative complications. Other research studies will ensure that the wearable sensors are as accurate as monitors used in Intensive Care Units. Developing this device will make surgery safer, improve postoperative recovery, and presents an incredible opportunity to grow the MedTech industry in Aotearoa New Zealand.
	Boosting crop growth and yield by improving nitrogen uptake and use	Dr Paul Harris	3	$999,999	Nitrogen (N) is an important nutrient found in all living things, including plants and healthy soils. In plants, nitrogen is essential for growth. Agricultural productivity is improved by the application of nitrogen as a fertiliser, however even the best-bred crops fail to capture 50-70% of added nitrogen, yet don't benefit from excess N. This wasted nitrogen causes huge ecological and environmental damage e.g. higher greenhouse gas emissions and pollution of waterways. Globally, there is an urgent need for nitrogen fertiliser to be used more efficiently while maintaining or increasing food production. This can be achieved by a new method for boosting nitrogen uptake and absorption by plants. we have discovered biostimulants that increase the uptake and use of nitrogen in plants. These are plants' "hunger signals" for nitrogen. Our research has shown that these peptides can be effectively applied to plants to boost growth. Our research will develop and deliver potent peptides that mimic peptide coding genes (called peptide analogues) that can efficiently activate the uptake and use of nitrogen in plants, thus increasing growth and yield. The aim is to develop effective, safe, affordable agrochemicals that can be applied to boost crop productivity. This research programme will deliver significant benefits to New Zealand agriculture and the environment – a win-win situation. Improved nitrogen use efficiency will boost crop and pasture productivity while decreasing nitrogen leaching from soil and into waterways. There will be huge demand for our innovative peptide analogue as the issue of food security and nitrogen leaching into the environment is global.

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	Developing Biodegradable Quaternary Ammonium Biocides for Sustainable NZ Marine Biosecurity	Alan Cameron	3	$1,000,000	Invasive marine pests and diseases have a history of devastating harm to NZ's maritime industries and environment. Biosecurity is critical for economic resilience and growth of NZ. We are targeting the critical gap in marine biosecurity response systems – the lack of suitable and effective tools for marine pest and disease control. In this project we will develop the first biocides specifically for management and eradication of marine pests (e.g., the current incursion of 'killer algae' at Aotea) and diseases (e.g. Bonamia ostrea which ceased flat oyster farming in NZ and threatens the iconic Bluff oyster fishery), to enable effective and responsible biosecurity responses. The biocides developed herein will be prepared by harnessing a novel 'green chemistry' method of preparation and provides opportunity for environmentally responsible manufacturing, including the use of climate-friendly CO2 consuming processes. Leveraging this new manufacturing platform, our biocides will harness readily biodegradable motifs, allowing their effective break down to inactivated species that significantly reduces the collateral harm, environmental accumulation and damage to delicate ecosystems and microbial communities (e.g. in soil/sediment) that is known to occur with many of the currently available mainstay biocides. We will develop our biodegradable biocides and methods of application in partnership with multiple stakeholders in NZ, including Iwi, to ensure the ultimate outcome for NZ. The potential impact of our new technology will be far reaching and not only has implications for biosecurity internationally, but will be highly applicable to a range of sectors including: agriculture/dairy industry, hospitality, cosmetics, clinical disinfection and personal hygiene, the latter two of which have become increasingly relevant in the face of the global COVID-19 pandemic. Primary contact: Dr Alan Cameron, email: alan.cameron@auckland.ac.nz
	Developing insulin signalling inhibitors for rapid weight loss	Dr Troy Merry	2	$999,998	Having excess fat mass is associated with an increased risk of numerous diseases including heart disease, diabetes and cancer. However, loosing and maintaining lost weight through diet and exercise is very difficult, and the very few pharmaceutical options help have uncomfortable side effects, low effectiveness in the long-term or need to be injected. In this project we will develop a new class of weight loss pills to assist with the long-term maintenance of a healthy body weight. We have recently discovered that a drug that is already used clinically to inhibit an enzyme called PI3K can cause rapid and sustained loss of fat in in obese mice. We have developed our own versions of this drug that are more specific and therefore should have less side effects. In this application we will determine the safety and efficacy of these drugs, and optimise the dosing in to determine if they are viable drugs to aid in weight loss. One of the ways through which these dugs act to support weight loss is by reducing the ability of the body to used sugar, leading to high blood sugar. While long-term high blood sugar can be of clinical concern we have designed new co-treatments to avoid this and therefore improve the safety of these drugs. The weight loss industry has a annual revenue in the hundards of millions, and a large proportion of the global population are currently trying to lose weight. Therefore obese, developing, testing and producing a new effective weight loss pill locally here in New Zealand will have considerable economic and health benefits for the country.
	Empathic Characters for Cognitive Rehabilitation	Professor Mark Billinghurst	3	$999,979	This research explores the creation of Empathic Virtual Characters (EVCs) for enhancing VR therapy. This will be the first time that EVCs have been used in VR for cognitive therapy, and could transform the rehabilitation industry, adding value to NZ's knowledge intensive industry. EVCs combine physiological sensors (EEG, GSR, heart rate, eye- and face tracking) with AI to measure the patient's emotional and cognitive state. This provides valuable feedback to patient and clinician, especially compared to current practice of self-reported measures, and could be used to adapt the VR therapy. The aim is to provide customised therapy for the patient in a simulated social situation and understand how patients respond. The EVC can adapt to the client, such as being represented as Māori and speaking in Te Reo. The EVCs can be used in a collaborative VR setting to support remote real therapists, enhancing access to rehabilitation services. The initial focus will be on therapy for people with post traumatic brain injury (TBI), with cognitive fatigue; a long term lack of mental energy. During their rehabilitation, people with TBI work closely with health care providers, often for many months in a time consuming process, which is difficult in remote regions with limited access to therapists. We will involve user groups, including people with lived experience (using the Burwood Academy consultation network) and clinicians from Laura Fergusson Brain Injury Trust, and will commercialise the research through game company CerebralFix. We include Māori perspective through engagement with kaupapa Māori organization's Iwi United Engaged Limited and He Waka Tapu. The outcome will be a tool that could transform therapeutic healthcare, enabling patients to receive support wherever they are and whenever they need it.

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	High-energy-density Rechargeable Seawater Batteries for Marine Renewable Energy Storage	Dr Shanghai Wei	3	$1,000,000	Aotearoa New Zealand's marine and aquaculture industries aim to grow to a $3Billion industry by 2030. These industries are also aiming to minimize their carbon footprint. Harnessing marine renewable energy (MRE), i.e. energy collected from wind, tides, salinity gradients and sunlight over the surface of the ocean is essential for decarbonisation of the marine and aquaculture sectors. This is especially important for Aotearoa New Zealand, which has an Exclusive Economic Zone approximately 15 times larger than its land area. Efficient storage of MRE is essential for meeting the energy needs of the growing marine and aquaculture sectors. Currently, lead-acid batteries (LABs), and lithium-ion batteries (LIBs) are used in these sectors, providing a power source to a wide range of underwater robots, sensors and inspection systems, as well as offering micro-grid scale energy storage. These battery technologies have limitations due to low energy density (LABs) and non-recyclability (LIBs), making them less than ideal for MRE storage and improving the sustainability/resilience of our aquaculture and marine industries. This project aims to design and develop rechargeable seawater batteries (SWBs), a new battery technology that uses seawater as an active battery component. SWBs are considered very promising storage systems for marine renewable energy (MRE) storage. Our approach will combine the advantages of metal-air batteries and magnesium-ion rechargeable battery technologies. Novel alloys will be fabricated and applied as battery electrode materials, and hybrid rechargeable seawater batteries will be constructed. The proposed work builds on our current fundamental battery research and will exploit unique methods to design and develop rechargeable batteries for MRE storage, sustainable aquaculture and the marine industry. This research will deliver environmentally friendly batteries with high-energy-density, low-cost and 100% recyclability.
	Octopus a Novel High Value Species for NZ Aquaculture	Dr Andrew Jeffs	3	$1,000,000	This research will develop novel larval culture technology to provide a source of juvenile octopus for ongrowing that will underpin the emergence of a globally unique octopus aquaculture industry in New Zealand, while also driving greater sustainability in the seafood sector. A team of leading octopus aquaculture researchers from Japan, Australia and New Zealand will collaborate to build on recent significant local advances in culturing New Zealand octopus species. These recent advances include the development of new captive breeding techniques, artificial egg incubation and extended hatching technologies, and feeding octopus larvae with formulated feed. Further advances from this research will deliver the technology to supply juvenile octopus that can be grown rapidly to market size in aquaculture, reaching over 1.5 kg in less than a year. The advanced technologies for culturing marine larvae will also have ongoing benefits for the further diversification of New Zealand's aquaculture industry. Octopus aquaculture will leverage off the capacity of the existing Greenshell™ mussel industry, utilising expertise, excess farm space, and more than 5,000 tonnes of waste mussels a year will be converted to octopus food. The advent of this new industry will serve to diversify New Zealand's aquaculture sector by producing and supplying high-value octopus products into a global market that is characterised by ever increasing prices and demand, and constrained supply from wild octopus fisheries. The emergence of a new octopus aquaculture industry in New Zealand will provide new opportunities for Māori participants in the sector with the potential for rapid growth to over $100M within a decade, making an important contribution toward the sector achieving its growth target of becoming a $3 billion industry by 2035.
	Predictive tools to enable climate resilience for tītī/muttonbirds across Aotearoa.	Dr Brendon Dunphy	3	$1,000,000	New Zealand is the seabird capital of the world, yet 90% of our seabirds are threatened with extinction. Climate change and El Niño are known threats but their specific impacts on seabird stress and breeding are poorly described. This gap severely hampers our ability to ensure climate resilience in seabird populations. To improve our ability to support seabird populations, researchers from The University of Auckland, Auckland University of Technology, DOC, Manaaki Whenua/Landcare Research and Tamaki Paenga Hira/Auckland War Memorial Museum are coming together to study tītī/sooty shearwater (*Ardenna griseus*). This species has immense cultural, economic, and ecological importance, so a project has been codesigned with Māori muttonbirding communities, eager to ensure that the mana and mauri of tītī persists in a warming future. A key question is how will climate change and El Niño affect tītī stress levels/breeding in a warming future, given that stress reduces breeding success? The team will investigate whether: *1) tītī stress has increased over the last 130 years, 2) El Niño and warmer seas lift tītī stress levels, 3) northern tītī colonies are more stressed than southern.* The team will track migrating/breeding tītī over both hemispheres using the International Space Station. Bird tracks will be matched to satellite data on environmental conditions and bird stress assessed from feathers. We will develop a predictive model of how bird breeding success is affected by ocean conditions. This will provide rapid predictions of 'bad seasons' for DOC, kaitiaki and conservation groups, delivering greater agility in seabird management approaches and optimisation of future workplans to cope with climate change.

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University of Canterbury	A simple capillaric platform for real-time diagnostic devices: In-house wine testing as proof-of-principle	Dr Volker Nock	3	$1,000,000	The key elements to run a pre-programmed complex multistep enzymatic assay in capillaric devices are yet to be developed. The new elements needed include automated and simple switch-on, switch-off, mixing, timed incubation, and measurement functionalities. Leveraging our new IP in capillaric devices and expertise in diagnostic assays, we will develop these elements and create an easy-to-use chip for in-house, quantitative real-time testing of grape juice, wine ferments, or finished wines as proof-of-principle. Wine makers tell us this is needed to reduce uncertainty, reduce production and analytical costs, and improve productivity. New Zealand winemakers already spend ~$60M p.a. on assays, yet produce just 1% of wines globally—if we are successful in developing our capillaric platform, then there is a significant international market for assay devices to be manufactured here in New Zealand and exported to wine makers overseas. If successful in wine making, our platform will be adapted for the much larger biomedical diagnostics sector (*e.g.,* ELISAs), or the environmental monitoring sector (*e.g.*, nitrate sensing). Our team consists of experts in assay design, microfluidics, wine chemistry, diagnostics, device engineering and commercialisation. We partner with wine makers and the wine industry through the Bragato Research Institute, which is the New Zealand Winegrowers' research centre.
	Creating Soilless Precision Farming via Ultraclean Water Production: Invention of Weather-adapting Green-tech	Alex Yip	3	$1,000,000	Soilless hydroponic farming shields vulnerable produce from the mounting effects of changing weather patterns, rising surface temperatures, natural disasters, etc. It enables growing food closer to large population centres and reduces the "food miles" associated with distribution, reducing the carbon footprint (low emissions). However, a critical determinative factor in hydroponics cultivation is water quality. The recirculated hydroponics water must be treated for emerging micropollutants that, besides root exudates, may also contain pesticides, endocrine-disrupting chemicals (e.g., plastics leaching) and fluorinated substances from continuous accumulation. This project will invent a new photoelectrochemical water-treatment GreenTech that removes micropollutants effectively. The weather-adapting feature of the technology allows water to be recirculated sustainably or safely discharged. By protecting clean water as taonga (treasure), our GreenTech enables safe and sustainable soilless farming, providing climate-resilient economic growth, e.g., off-season cultivation of high-value produce or microgreens, etc. Once developed, the water-treatment device will serve as a general platform for the continuous development of photoelectrochemical systems for other energy and environmental applications, including hydrogen generation, CO_2 and nitrate removal, etc. Our project team is comprised of national and internationally leading researchers in the area of micro/mesoporous materials, photocatalysis, electrochemistry, electronic devices, hydroponics, and Mātauranga Māori. Our industry partners include agri-device manufacturers, NZ water supply advisors and demonstration end-users.
	High-efficiency Gallium Oxide Power Electronics for New Zealand's Zero Net Emissions Future	Martin Allen	3	$1,000,000	New Zealand's transition to a 100% renewable energy economy requires new power electronic devices that are faster, cheaper, and more efficient at handling our precious wind, solar, geothermal, and hydro electricity resources. More efficient and faster power electronic devices are needed to reduce the costs and energy losses so that as little as possible is wasted. A multidisciplinary expert team of scientists and electrical engineers from around the world will work on the development of an exciting new power electronic semiconductor material called gallium oxide. This work has the potential to significantly improve the costs and efficiency of generating, distributing, and using renewable electricity for all our energy needs. This will create high value jobs In New Zealand and will be a big step towards meeting the New Zealand Government's targets of 100% renewable energy by 2035 and net zero emissions by 2050. Success in this endeavour represents a huge commercial opportunity as the world switches to renewable electrical energy, with the power electronics industry projected to grow to US$ 44.2 billion by 2025.
	Innovating climate risk assessment: A system-wide, geospatial approach for councils and communities	Tom Logan	3	$1,000,000	Governments worldwide are ill-equipped to understand their risk from climate change, partly due to existing limitations in risk science. We propose to address these limitations and fundamentally shift how risk analysis is conducted, enabling local governments globally to understand and adapt to their risks. In NZ, the Zero Carbon Act (2019) requires local authorities to assess their climate risks - likely needed for the 2026 national climate change risk assessment. The NZ government considers risks using the following interdependent value domains: Natural environment, Built environment, Human, Economic, and Governance. This interdependence means that an impact on one will incur consequences to others. However, while existing risk assessments and governmental guidance documents have recognised this interdependence (critical from Te Ao Māori perspectives), none successfully manage these complexities. Additionally, existing assessments and guidance fail to sufficiently address the changing risk over time; consider the risk spatially (essential for evaluating adaptation options); evaluate impacts from compounding and cascading hazards; and address the inherent uncertainty. These limitations are not confined to NZ; a worldwide review of climate adaptation plans concluded they are "unlikely to be effective" (Olazabal & Ruiz De Gopegui, 2021), indicating a global shortage of adequate guidance. We propose a Knowledge Hub for Climate Risk Analysis Innovation to address these limitations. This work will set the global standard for assessing climate risk to maximise societal benefits for communities worldwide.

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	Low-carbon and seismically resilient solutions for 3D concrete printed homes	Giuseppe Loporcaro	3	$999,999	New Zealand (NZ) has an ongoing housing crisis. The strong demand and supply chain issues have made housing an unsustainable problem with construction delays and an increase in material costs. Also, the construction industry has lacked innovation and it is moving at a slow pace compared to other industries. In addition, the global construction industry is responsible for 37% of CO_2 emissions. Digital fabrication in construction is a promising technology that could disrupt the current industry by producing high-quality, fast and integrated new design and construction processes. Research shows that digital fabrication and 3D printing of concrete could build 75% faster, emit 40% less CO_2 and produce 70% less waste than traditional construction methods. The 3D-concrete printing technologies developed overseas cannot be immediately implemented in NZ because of the unique seismicity of the country. This research aims to develop a 3D-concrete printing technology for residential houses that are low-carbon and seismic resilient. The new technology created would reduce the CO_2 emissions of homes in two ways: 1) by developing 3D-printable mixes that use locally-sourced waste materials such as mussel shells and paper sludge ash and low- CO_2 producing magnesium-based concrete; 2) by developing earthquake-resilient 3D printed structural configurations that are optimised to reduce materials usage and waste while improving structural efficiency. We aim to develop design and construction guidelines for 3D-concrete printed houses. The guidelines will enable a new approach to construction in NZ which is cheaper and faster and can help to address the current housing crisis. We aim to provide a pathway to utilise waste products aligned with a circular and sustainable economy that also meets targets to address climate change.
University of Otago	Avoiding carbon lock-in: Understanding the long-term consequences of low-carbon pathways for buildings	Dr Michael Jack	3	$1,000,000	Buildings are directly and indirectly responsible for up to 20% of NZ's greenhouse gas emissions. They are also the main cause of winter electricity demand peaks which are a key barrier to the achievement of high levels of renewable electricity supply – a critical component on NZ's overall decarbonisation strategy. New low-carbon options, such as nearly-zero or net-zero energy (that self-generate renewable energy) buildings have the potential to significantly reduce operational emissions, but they could also increase embodied carbon in construction materials and have negative or positive impacts on the electricity grid. To avoid "lock-in" of carbon emissions in long-lived buildings and electricity grid infrastructure, there is an urgent need to identify the most effective low-carbon pathways for buildings in NZ. Current modelling tools are either focused on single buildings or extrapolate from current national heating demand and are unable to explore large-scale uptake of transformative low-carbon options. Leveraging synergies between the team's recent research, we will overcome limitations in current modelling tools to create the world's first national building scenario modelling tool for assessing the impact of nearly-zero or net-zero energy buildings on the regional and national electricity system and exploring the trade-off between operational and embodied energy/carbon. The insights from our research will transform NZ building standards for new and retrofitted buildings, inform government and industry strategies aimed at decarbonizing NZ's energy system and help catalyze the creation of low-carbon, future-proof buildings by the building sector. This research will yield a permanent reduction in greenhouse emissions from buildings and significantly reduce the costs of decarbonization for NZ. It will also result in significant co-benefits in health and energy costs and poverty reduction.
	Cell free synthetic exosomes incorporated nanomatrix for the treatment of ischaemic diabetic ulcer	Associate Professor Rajesh Katare	3	$999,996	Chronic non-healing ulcers represent a relevant clinical and socioeconomic burden. Diabetic patients with foot ulcers associated with narrowing of blood vessels in the limb manifest the worst outcome with the highest amputation and mortality rates. Although the efficacy of topical gel formulation of various growth factors is currently in clinical use, they are not effective in chronic diabetic ulcers. Our project will explore the novel therapeutic option for chronic diabetic ulcers using molecular modulators. We will develop an innovative combinatorial approach of incorporation of the molecular modulators with biopolymeric nanomatrix to increase the efficacy and stability after topical application on the ulcer. This will be the world-first off-the-shelf product bringing direct economy and training for high skilled force in New Zealand. Further, reducing the amputation rates will have a marked improvement on the quality of these patients, thereby reducing the burden on the health sector.

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	Forecasting future megaquakes on New Zealand's biggest fault: The Hikurangi subduction zone	Associate Professor Ting Wang	3	$1,000,000	Subduction zones, where one tectonic plate is forced underneath another, produce the world's deadliest and most destructive earthquakes and tsunamis, as demonstrated by the 2011 Magnitude 9 Tohoku-Oki earthquake in Japan. In New Zealand, geological records reveal that great subduction earthquakes (magnitude>=8) have occurred regularly along the Hikurangi Subduction Zone beneath the eastern North Island, where the Pacific tectonic plate thrusts beneath the Australian plate. Recent overseas research has shown that major subduction zone earthquakes are sometimes preceded by phenomena known as slow slip events (SSEs, essentially earthquakes in slow motion). Following the 2016 magnitude 7.8 Kaikōura earthquake, SSEs were immediately triggered along the full length of the Hikurangi Subduction Zone, sparking demand from central government for scientists to determine the likelihood of a great earthquake in central New Zealand following on from the SSEs. This project aims to develop statistical models to clarify the relationship between SSEs and earthquake occurrence, and the impact of SSEs on near-term great earthquake forecasts. We will analyse existing geodetic and seismic data to obtain new catalogues of SSEs and seismic swarms along the Hikurangi Subduction Zone, and develop tools to forecast SSEs and great earthquakes. Being able to forecast when great earthquakes will next occur is of profound importance for providing critical early warnings that will ensure the preservation of our workforce, infrastructure, and economic. The ability to better forecast future Hikurangi Subduction Zone earthquakes will place New Zealand at the forefront of subduction zone forecasting worldwide, and enable the country to better anticipate and reduce potential disruption, damage and casualties. This will enhance our ability to undertake critical early warnings for damaging earthquakes, and inform decision-making for risk mitigation.
	Moriori, Music and Manawa: Engaging Multisensory Experiences for Indigenous Cultural Revitalisation	Dr Gianna Savoie	2	$1,000,000	Aotearoa shines as gem of cultural richness, but one facet of its history has yet to be illuminated – the story of our indigenous Moriori. Cultural health is interlaced with national health and when one erodes, so does the other. It is often forgotten that New Zealand has not one, but two native peoples, and few have suffered such persistent and damaging myths and misinformation about their cultural heritage as the Moriori of Rēkohu (Chatham Islands). False narratives perpetuated for generations have misrepresented them as a people who were conquered, cast away and ultimately driven to extinction. The truth is that Moriori are very much a living indigenous community with a history steeped in connection to the natural world – the land, the wind, the sea. Highly adapted to their island environment and bounty of natural resources, they developed their own specialised culture, traditions, language and music – all now at risk of being lost or forgotten. In a marriage of indigenous knowledge and cutting-edge technology, this groundbreaking project, co-designed with and directed by the Hokotehi Moriori Trust, serves to revitalise Moriori culture through a multisensory, cross-cultural approach. Employing a range of multimedia replication technologies including acoustic sampling, 3D printing, extended reality (XR) and 360º filmmaking, our international team of contributors will co-design and create an immersive experience to be shared with the global public. It is research that embraces *totohunga* (heart) by engaging the public in a project that amplifies the Moriori story while creating a scalable model for advancing cultural understanding everywhere.
	Recovery of high-value, natural flavour compounds from untapped food processing sources	Graham Eyres	3	$1,000,000	Flavour compounds contribute to the sensory properties of a food and to consumer enjoyment - for example, think of the smell of freshly baked bread. For us to smell them, such compounds must be volatile, which means that they can be released into the air and move to the odour receptors in our nose. Many different volatile aroma compounds combine to form a particular flavour. Natural flavours can be expensive to isolate from raw materials and this coupled with their high demand means that they command a premium price. Our idea is to use the waste streams produced by food processing plants as novel sources of raw materials from which to harvest natural volatile compounds, which can subsequently be sold as natural flavours or flavour components. The large size of our milk powder industry gives New Zealand a competitive advantage in mining the waste streams that dairy factories produce as a source of flavour compounds, as no where else in the world is milk processed in such large volumes for export. Not only will this research generate an additional revenue stream from milk, it will lead to the development of high-value knowledge-intensive natural flavour industry. Further, once it has been determined that flavour compounds can be extracted and stabilised from dairy waste streams, the technologies and know-how we develop could be applied to the waste streams generated by other industries.
	Tere Tīpako Tio: Rapid Extensive Antarctic Ice Sampling Aotearoa	David Prior	3	$999,999	Rapid melting of floating ice shelves is speeding up the flow of ice from Antarctica into the ocean. Planning a climate change resilient New Zealand requires the most realistic ice sheet models possible, to predict future ice loss, consequent sea-level rise and changes in Southern Ocean circulation. Physical properties of the ice, such as its plasticity and elasticity, are critical inputs to the predictive models. Yet we have virtually no ice samples available to study the physical properties, because existing ice sampling approaches are slow, cumbersome and expensive. The models are thus limited in how they represent this critical component. We propose to build new, portable, low-cost drilling tools for rapid sampling of shallow ice (<200m), combining existing and newly developed technologies. Access holes will be drilled using a small hot water drill, a proven method. After water is pumped from the hole, we will collect small samples from multiple depths using a newly developed sidewall coring tool. Development systems will be designed and built by teams of engineering students, with mentorship from local and international experts. Students will be involved in testing, application and outreach. To develop and test the technologies, we will collect ice samples at multiple depths from 30 sites across the floating Northern McMurdo ice shelf. Conventional coring would allow sampling of just one or two sites in the same time. Accessing multiple sites in a single field season is important because ice properties are variable and change over time due to ice flow. This will be the first extensive ice sampling across any ice shelf, leading towards better understanding, better models and better prediction of how the Antarctic ice sheet will respond to climate change.

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University of Waikato	A ligase-based solution for non-natural nucleic acid synthesis	Dr Adele Williamson	3	$1,000,000	Xeno-Nucleic-Acids (XNAs) are artificial equivalents of natural genetic material DNA and RNA and have potential applications in synthetic biology, nanotechnology therapeutics and diagnostics. They behave in a similar way to natural nucleic-acids folding into double-helices and storing information, but they can have much greater chemical diversity and are often more stable in biological fluids like blood and saliva. This makes XNAs extremely useful for biotechnological applications such as next-generation aptamers. Aptamers are pieces of nucleic acid that fold up into 3D structures and can bind other to molecules and have potential use as biosensors or drugs. XNA-aptamers are better suited for this purpose than ones built from DNA because they bind tighter and are not degraded as easily. One of the biggest issues with XNAs is they are difficult to synthesize: our Smart Idea will solve this problem by discovering and engineering enzymes to build large XNAs from small synthetic pieces. We plan to use DNA ligases, enzymes that join breaks in double-stranded DNA in nature. We will begin with ligases that we find in the genomes of bacteria and viruses from extreme environments like Antarctica and geothermal regions of Aotearoa New Zealand, working together with iwi and hapū who are kaitiaki of these taonga. We will also determine the molecular details and 3D shape of how of these enzymes bind to XNAs so we can tweak them to work even better. Our ultimate goal is to provide an enzymatic toolkit for synthesis of XNAs that can be used to find solutions for New Zealand-specific problems like pest detection, water-quality monitoring and healthcare.
	Enhanced rock weathering for large-scale capture of carbon dioxide in Aotearoa	Dr Terry Isson	3	$1,000,000	Atmospheric carbon dioxide (CO_2) removal (CDR) over the next century is required to avoid devastating climate impacts in Aotearoa New Zealand and globally. Yet, few tenable large-scale CDR applications exist, and the lack of significant point CO_2 emission sources has thus far limited CDR in Aotearoa. Enhanced rock weathering (ERW) has been proposed as a viable strategy for global scale carbon capture, with recent modelling estimating net 0.5-5 Gt CO_2 yr^{-1} potential. Yet, there is currently little to no field data to support the rates of capture deemed possible. Aotearoa plays host to warm, wet climates, and ideal volcanic rock type such as basalt and dunite (high capture-capacity-to-weight-ratio), making for an ideal locality to constrain the true potential of ERW for carbon capture. Through this project, we will conduct the first ever large-scale ERW field trial in collaboration with Ngāti Pūkenga and Ngāi Tahu, to determine the potential of ERW to take us one step closer to achieving carbon neutrality—before it is too late.
	Lightweight compliant mechanism robotic grippers for fruit harvesting	Ajit Pal Singh	3	$1,000,000	This Smart Idea will produce a new generation of light, inexpensive, efficient and reliable harvesting grippers using advanced design and manufacturing techniques. Current harvesting grippers transfer motion and force through mechanisms that consist of multiple rigid parts connected by movable joints. These joints, when used repeatedly, suffer from friction and wear-induced failure. They are also heavy, expensive and require assembly, lubrication, and regular maintenance, especially in the harsh outdoor environment in which they mostly operate. Our novel approach to address these issues will combine the complementary strengths of compliant mechanisms, generative design, and additive manufacturing to create a cost-effective and robust robotic harvesting gripper that cannot be produced by any other means. The key aspect will be to integrate an advanced algorithm-driven generative design approach with a complex compliant mechanism node geometry creation process. This will be achieved by identifying critical interfaces between the flexure-joint segments (nodes) and potential areas where generative algorithms are applicable. With successful development of computational generative models, a fully optimized additive manufacturing processing route to fabricate complex organic-shaped compliant gripper structures will be established. Additionally, techniques to verify the functionality of the 3D-printed prototypes and to validate fatigue performance will also be developed. Success will provide significant advances in the field of robotic grippers, bridging the gap between innovative design and advanced manufacturing of compliant mechanisms. The new robotic gripper technology will provide benefits to many New Zealand companies (including Robotics Plus, Axis7) through our existing and future partnerships. Furthermore, it will **create opportunities to upskill fruit picking workforce into higher value jobs (incl. Māori orchardists)** and help solve New Zealand's horticulture labour issues and provide opportunities for high-value exports in a rapidly growing sector.
	Spatially mapping galaxiid nests with scent detection dogs and unmanned aerial vehicles	Associate Professor Nicholas Ling	3	$1,000,000	Whitebait were once so plentiful in Aotearoa New Zealand that they were used as fertiliser and canned for export. However, it is widely acknowledged that the whitebait fishery has declined substantially since those early days and that modification and loss of habitat is a key threat. The main whitebait species (īnanga) spawns terrestrially in riparian vegetation during spring high tides, with the eggs hatching one month later on a following spring tide. Finding the nests of īnanga by visual searching is laborious and plagued with error due to potential confusion with eggs of other animals like slugs and snails. We have a well-established programme at the University of Waikato training scent-detection dogs for environmental and medical research. This project will use trained dogs to detect and geolocate the nests of īnanga in riparian vegetation of rivers and estuaries combined with detailed aerial mapping of vegetation and physical habitat using aerial drone photography and other remote sensing data such as digital elevation and satellite data. Our ability to rapidly locate īnanga nests and characterise their associated habitat will provide detailed habitat models that will provide greater prediction of potential spawning habitat and assessment of the usefulness of riparian restoration to protect and enhance whitebait spawning zones. Ultimately, we expect this approach will be designed in collaboration with end-users, including regional councils, iwi and community groups, to restore and protect whitebait spawning and enhance the harvest and sustainability of the whitebait fishery.

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Organisation	Title	Science Leader(s)	Duration *(years)*	Contract Value *(GST excl)*	Applicant's Public Statement
Victoria University of Wellington	Antibody therapy to control viruses and Varroa parasites in honey bees	Phil Lester	3	$999,999	Honey bees contribute an estimated $5 billion to NZ's primary industries. One of the greatest threats to the honey bee industry, here and internationally, is the parasitic varroa mite and the viral disease it spreads called Deformed wing virus (DWV). Together, varroa and DWV are the leading cause of death to honey bees worldwide. The current approach to controlling varroa and this virus is a chemical pesticide that is becoming ineffective. Our research will develop a safe, effective and commercially viable method to control DWV and mitigate the effects of the varroa. Our method uses immunotherapy for bees. Immunoglobulin (IgY) antibodies have previously been developed to treat infections including influenza. The antibodies are cheap to produce and can be stored for long periods. This method of pest control also leaves no synthetic chemical residues in honey, so it has no ill effects for humans or bees. Our preliminary research indicates these antibodies have considerable promise. We will develop a IgY antibody treatment and test its effects on the varroa parasite's reproduction and fitness. Our treatment will be in a form that can be easily fed to bees by beekeepers. During field trials we will confirm that the antibody treatment is safe for bees and enhances their productivity. Once our research is complete, we will work with the Ministry for Primary Industries and Environment Protection Agency to authorise the legal use of the treatment by beekeepers. We will then develop a pathway to commercially produce the new treatment. Our goal is to develop an environmentally safe method to control this pest and disease in honey bees. However, this approach could become a model way to control many other pest species.
	Detecting aneuploidy from embryo secretions	Janet Pitman	3	$999,999	The recent finding that cells package genetic material into membrane-bound microvesicles for secretion has initiated a new era of biomarker discovery. This discovery has led to novel methods of disease detection that are either minimally- or non-invasive. The embryo is no exception and microvesicles packed with genetic material and secreted into their surrounding environment provide a snap-shot of their genetic make-up. Our research will use this phenomenon to address a significant problem for the human fertility industry. Half of human embryos generated by in vitro fertilisation (IVF) in fertility clinics have an incorrect number of chromosomes (aneuploid). The transfer of aneuploid embryos into the uterus results in embryo loss, which is emotionally and financially devastating to the recipients. Whilst an aneuploidy test is available which extracts cells from the embryo, it is invasive, risky to low quality embryos, expensive and has a long result turn-around time. These limitations mean very few people choose to get their embryos tested. We will assess the microvesicle-encapsulated genetic material secreted from IVF-embryos to determine if they accurately indicate their chromosomal numbers. During this work, we will identify secreted biomarkers of specific aneuploidies for the first time and develop a simple, rapid and cheap test for their detection. The revolutionary advantage of this test is that it only tests the medium in which the embryos are cultured in, leaving the embryo undisturbed. Such a test is highly desirable to the international fertility industry and we will work with industry partners and commercial genetic testing companies to develop a commercially-available test. The down-stream benefits of this non-invasive test is that more people will choose to get their embryos tested leading to an improved IVF success rate.
	Efficient spintronic terahertz emitter for beyond-the-lab applications of terahertz spectroscopy	Dr Simon Granville	3	$999,911	The Terahertz (THz) frequency range of the electromagnetic spectrum, sitting between infrared light and microwaves, has vast untapped potential for scientific, industrial and environmental uses - from detecting the evolution of galaxies to high bandwidth telecommunications and monitoring concentrations of atmospheric gases affected by climate change. The ability of THz waves to penetrate biomolecules and probe them without causing damage also makes them ideal for many areas critical to New Zealand such as agriculture, food production and biomedical imaging. However existing technologies for generating THz waves are severely limited in the range of frequencies they can produce and the instruments for doing so are bulky, expensive and little used outside of research labs. For that reason, this part of the spectrum has long been known as the 'THz gap', waiting for the technological advances that will finally open this underutilised region to its myriad beneficial uses. We will develop a source of THz waves that covers the full range of frequencies in this spectrum, using a novel technique of generating THz from magnetic materials. Our new technology will overcome the limitations of existing sources and will lead to THz technologies that are affordable and suitable for use in industrial settings. We aim to stimulate the growth of an entirely new high-value and high-productivity industry in New Zealand based on the manufacture and use of THz technologies. Our goal is for New Zealand to become a global hub for THz technology R&D, manufacturing and services for current and future industries.
	Plant-based bioactives for protecting our crops and ecosystems	Professor Monica Gerth	3	$1,000,000	Phytophthora is a genus of microorganisms that cause devastating dieback and root-rot diseases in thousands of plants worldwide. The economic impact of Phytophthora diseases on crops and native ecosystems is billions of dollars per annum, and these impacts are predicted to worsen with climate change. Here in Aotearoa New Zealand, a recently identified species Phytophthora agathidicida is threatening kauri (Agathis australis), which are treasured, long-lived native conifers. Whereas another Phytophthora species (P. cinnamomi) causes root rot in key NZ crops such as avocados. These pathogens are extremely difficult to control using existing agrichemicals, and the effectiveness of the few available treatments is jeopardized by increasing rates of resistance. Using a bi-cultural approach, our team has identified naturally occurring compounds from native New Zealand plants that inhibit the growth and survival of Phytophthora pathogens (in the laboratory, at least!). Here, we will build upon this work – and explore how to take these results from the laboratory to the field. Our ultimate goal is to have formulated plant extracts that are safe, effective, and can be used to control Phytophthora diseases in our fields and forests.

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X-craft Enterprises Limited	Robotic fish to enable effective coastal kaitiakitanga: information is power	Philip Solaris	3	$999,999	Coastal ecosystems are valuable, ecologically, economically and culturally. However, coastal zones worldwide are under threat from ocean warming, acidification, sedimentation, coastal development, over-fishing, and pollution. This project will develop new engineering technology to create prototype free-swimming (untethered) "robot-fish" that swim using artificial muscles and have video cameras. We intent for these "underwater drones" to ultimately be able to operate automatically for days or months at a time gathering information on coastal habitats, fish and shellfish. This new information will enable coastal kaitiaki to balance wealth creation with stewardship and protection of Aotearoa New Zealand's precious coastline. The research is led by environmental seacraft company X-Craft, and involves NIWA, and three world-leading NZ research-engineering groups: Biomimetics Laboratory (Auckland University, artificial muscles), the Sustainable Energy Systems team (Victoria University Wellington, high-voltage rechargeable micro-power systems) and Auckland University of Technology (Artificial Intelligence).

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Organisation	Title	Science Leader(s)	Duration *(years)*	Contract Value *(GST excl)*	Applicant's Public Statement
Auckland University of Technology	Sustainable Earthquake Resilient Buildings for a Better Future	Dr Shahab Ramhormozian	5	$8,231,625	New Zealand is vulnerable to damaging earthquakes, recent examples being Christchurch in 2011 and Wellington in 2016. Modern buildings are designed/built to sustain controlled damage during severe earthquakes, protecting occupants but necessitating costly and time-consuming post-earthquake repair or replacement. The cost of rebuilding Christchurch was $40 billion while repairing Wellington is anticipated to cost $30 billion, not taking into account the cost of business disruption and environmental damage. There is an urgent need for sustainable and resilient buildings that can be rapidly reoccupied following major earthquakes. Conventional building solutions will be damaged and become unreliable after severe earthquakes, for example, demolition of the Christchurch CBD after 2011, while existing more resilient building solutions (e.g. base isolation) are expensive with limited applicability. This proposal will close the current gap by establishing easily built, cost-effective, sustainable, and highly resilient seismic solutions that can be applied to both new and existing buildings. These will implement semi-rigid friction-sliding connections instead of conventional rigid connections. These novel connections will become flexible during strong earthquakes, limiting earthquake-induced forces and dissipating earthquake-induced energy imposed/exerted on the building. They are based on three decades of R&D by the core research team into innovative earthquake structural solutions. The goal is to create solutions for sustainable earthquake-resistant buildings, avoiding structural damage and enabling speedy re-occupancy. These solutions, which will be implemented at the same cost as conventional solutions in both new and existing buildings, will revolutionise the long-term prospects for the resilience of all building types, both in New Zealand and around the world. They will be widely accessible on economic grounds due to their adaptability and versatility and low implementation cost, ensuring safer and more sustainable communities in seismic regions.
Cawthron Institute	Emerging aquatic diseases: a novel diagnostic pipeline and management framework	Kate Hutson	5	$9,969,137	Harmful aquatic diseases have destructive impacts on NZ's marine and freshwater animals and plants and represent a significant ongoing risk. Diseases can devastate wild and farmed seafood sectors, damage aquatic ecosystems, and the wellbeing of our communities. The number of aquatic disease investigations in Aotearoa/New Zealand doubled in the past five years, and most of these diseases take years to diagnose or a cause is never identified, undermining all management efforts. Disease emergence in our waterways is escalating under climate change and we need new and improved ways to prevent and respond to this threat effectively. Our Emerging Aquatic Diseases Research Programme will overcome some long-standing challenges to resolving aquatic disease causation. We will draw upon medical frameworks to develop and implement a new forensic approach for investigating aquatic disease that will enable reliable and timely diagnosis. This will provide the knowledge needed for effective collective action by scientists, government, and communities. We will focus on key steps in the diagnostic process to predict emerging disease trends, improve incident reporting, advance our ability to identify a short-list of suspects early in the diagnostic process, and better understand the factors that might be causing aquatic disease outbreaks. The programme will unite leading scientific expertise in aquatic animal health, biosecurity, microbiology (bacteriology, parasitology, and virology), genomics, cell culture, aquatic animal husbandry, and social science alongside mana whenua and government stakeholders. This new approach to aquatic disease investigation will build national resilience against aquatic disease by improving reliability and speed of our efforts to diagnose diseases and respond to them. These outcomes will ultimately protect our precious aquatic ecosystems, preserve aquatic cultural and social value, and safeguard our >$3B seafood industries.
NZ Heavy Engineering Research Association	*Developing a Construction 4.0 transformation of Aotearoa New Zealand's construction sector	Robert Amor	4	$10,270,359	Aotearoa New Zealand's construction industry reached over $20.5 billion in 2019, making it a major contributor to GDP and employment, as well as developer of critical national infrastructure. However, it is an industry that requires radical transformation and has long been criticised for its low productivity, inefficiencies, and significant contribution in New Zealand's carbon emissions. This project will deliver the high quality and technically challenging research required to create transformation in terms of productivity, quality, affordability and sustainability in this critical industry through adoption of Industry 4.0 approaches to provide better decision support throughout the supply and value chain. This will be achieved by developing a standardised data management protocol for the sector sitting above three research programs focused on Circular design, (e.g. design lead construction process, Smart construction and Monitoring 4.0. Four research themes (Mātauranga Māori, Healthy sustainability, Computing Technology and Technology Transfer) will underpin these research programs to ensure that they are linked in delivering outcomes of universal relevance to the Sector.

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Organisation	Title	Science Leader(s)	Duration *(years)*	Contract Value *(GST excl)*	Applicant's Public Statement
Landcare Research	Integrating trees to target zero carbon and add value to rural landscapes	Dr David Whitehead	5	$12,497,355	Action to help New Zealand meet its net zero carbon emissions target by 2050 has a current focus on the establishment of new forests. We propose that the targeted integration of isolated or small clusters of trees into low to mid-sloping grasslands will provide an alternative to large-scale conversion to exotic forests, with substantial economic increases in carbon credits and additional co-benefits for animal fodder and shelter, reduced erosion, increasing farm resilience to climate extremes, increased visual amenity, and the enabling of kaitiakitanga. We aim to test that this approach will lead to increases in biomass and soil carbon *stocks that exceed those for the same ground area of continuous forestry*, contributing significantly to low-emissions and climate-resilient agricultural practices. For the first time we will quantify the enhanced biomass and soil carbon stocks associated with edge effects at tree/grassland boundaries in hill country widespread in rural New Zealand. Across these boundaries we will determine the soil microbial mechanisms regulating decomposition and stabilisation of soil carbon using key soil properties and next-generation DNA metagenomics. We will then develop and validate microbially explicit ecosystem models to predict changes in carbon stocks at site scale. From this we will undertake quantitative scenario modelling, incorporating decision constraints by land managers, to predict the economic, environmental and cultural value of increased carbon stocks at landscape scale and recommend the optimal spatial establishment of tree clusters for benefits and their value across nature's contribution to people. Our research will strengthen the country's international reputation for action to mitigate and adapt to climate change, support landowners including Māori to deliver sustainable land management, enabling kaitiakitanga, well-being, and the prosperity of the rural sector.
	*Precision Pest Eradication – pest-selective control tools	Dr Brian Hopkins	5	$12,500,000	Worldwide, current widely used vertebrate pest control toxins are harmful to humans and non-target animals. Therefore, their use is being increasingly restricted or banned. There is a consequent growing global demand for safer, more selective toxins. We will develop selective toxins for high-precision, environmentally sound vertebrate pest control using cutting-edge science to invent new types of toxins that exploit physiological and metabolic differences between species. Our new products will help protect our environment by enhancing pest management, improve sustainability and productivity of our primary industries, and support Predator Free 2050 to achieve its aspirational goals. Within this programme, hapū/iwi will explore how Māori values inform their own policy positions about toxin use in te taiao. Our research will provide a new toxin manufacturing industry for Aotearoa New Zealand with potential to target global markets. This represents a significant economic opportunity for Aotearoa New Zealand, as we have the knowledge and reputation that give us a head start. We are the only team in the world seeking to develop toxin discovery technologies that target individual pest species. Our discovery research will develop new candidate toxins for mice, possums and stoats, which are significant threats to our native flora and fauna. Our ambitious research programme brings together New Zealand's best researchers in the field from the University of Auckland, Victoria University Wellington, and Manaaki Whenua – Landcare Research, supported by an international group of leading academics, and commercial, industrial and regulatory experts.
Lincoln University	Fungal volatile organic compounds for sustainable agriculture in a changing environment	Prof. John Hampton	5	$10,689,853	Environmental changes pose significant threats to New Zealand's primary production, generating a critical need for innovative, effective solutions to maintain production in the face of increasing drought, temperature and pathogen/pest attack. Our research programme will pioneer a new class of environmentally friendly plant protectant, naturally occurring fungal volatile organic compounds (FVOC). We will demonstrate that application of our FVOC products will reduce the negative impacts of climate change induced stress on plant production as well as increasing the plant's ability to tolerate attack from disease-causing microbes. The costs of recent drought events and reductions in pasture persistence to New Zealand's primary industry were ~$2 billion for the dairy, sheep and beef sectors. We will use the latest scientific research tools to help us understand FVOC-plant interactions, particularly molecular level changes which may be heritable, and thus transferable through generations via seed. This research will be conducted by a team at Lincoln University in conjunction with domestic (AgResearch, Scion, Otago, Massey and Canterbury Universities) and international (Singapore, Mexico, Austria, USA) research partners. We aim to deliver non-toxic, environmentally-safe alternatives to existing and phased-out agricultural chemicals. This will help future-proof Aotearoa's agricultural, horticultural and forestry production in the face of emerging climate change stressors.
Māori and Indigenous Analysis Limited	*Kaupapa Māori : Creating An Indigenous Model for System Change in Aotearoa	Leonie Pihama	5	$3,200,000	Kaupapa Māori : Creating An Indigenous Model for System Change in Aotearoa will examine the development and impact of Kaupapa Māori initiatives over the past forty years to provide an evidential base that informs the creation of systems, pathways and Kaupapa Māori arrangements that will be critical to transforming both private and public services, businesses and agencies in Aotearoa. Over the past few years members of the project team have been engaged with organisations and businesses within the public and private sphere to provide input and advice regarding Kaupapa Māori approaches. As such we are acutely aware of the need for the development of clear models and systems approaches that can be utilised to inform how this is undertaken. We are concerned that there is yet to be any significant research undertaken to identify the ways by which fundamental elements and components of Kaupapa Māori approaches can be applied to restructuring institutional arrangements and systems change models. A Kaupapa Māori approach to developing models for systems change will enable the realisation of the aspirations of whanau, hapū , iwi, Māori towards intergenerational wellbeing and supports the broader intentions of the current government as expressed within the governments Wellbeing approach. The overarching research question informing this project is: **What are the success factors within Kaupapa Māori that can inform innovative models for systems change that will transform inequities experienced by Māori in both public and private spheres and across sectors?**

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National Institute of Water and Atmospheric Research Limited	*Toitū ngā taonga waimāori: Cultural keystone species, Māori livelihoods and climate change	Dr Erica Williams	5	$11,279,000	Climate change is impacting our freshwater Cultural Keystone Species (CKS), habitats/ecosystems, biosecurity, water quality, land use and primary production, and disrupting Māori livelihoods and communities throughout Aotearoa-NZ. Complex environmental issues, such as mahinga kai and biodiversity loss, will be exacerbated by climate change and compounded by increasing conflicts between iwi/hapū food security and regional/national economic priorities. Māori understand intergenerational equity issues and the need for long-term solutions; however, more work is required by Māori in a safe cultural space to consider what their livelihoods may look like under a changing climate, including new relationships with future freshwater environments and CKS. To prepare for this, Maori want to understand how climate change will modify freshwater CKS communities (e.g., tuna, kōura, kākahi, kanakana/piharau, īnanga/pokotehe, pōrohe, kōaro), their interdependencies, and the diversity of socio-ecological-economic systems they support. This programme will evaluate magnitudes of change that CKS may experience, including spatiotemporal variation in species/cultural practice sensitivities, to forecast climate-related vulnerability patterns of species/cultural practices. This will inform the evaluation and implementation of dynamic evidence-based interventions that are targeted to the cultural contexts within which they will be applied. The programme responds to a diversity of Māori voices and research needs to deliver new transferrable approaches drawn from multiple knowledge systems. It will identify impacts we cannot avoid and co-design interventions to respond, strengthening resilience of whānau livelihoods, cultural practices and CKS – *Te mana o ngā taonga waimāori* – reflecting that these taonga tuku iho have mana in and of themselves and as such are beneficiaries of the research – Mō tātou, ā, mō kā uri, ā muri ake nei – for us, and our children after us.
Nga Uri O Te Ngahere Trust	Tino Rangatiratanga o Rātou Taonga Katoa	Garry Watson	3	$4,229,268	The Tino Rangatiratanga o Rātou Taonga Katoa research programme is derived from the guardianship responsibilities we have to protect Taonga, the treasures of Aotearoa, and address inequalities within our communities. It researches the rich history of Māori economic development immediately after first European contact, which created the foundation of primary production in Aotearoa and our first agriculture export, and it applies those te Ao Māori principles and practices within the industry, to create whenua based social enterprises that enhance environmental sustainability, delivering wellbeing, as opposed to revenue only, to primary producers. It draws together the wisdom of gifted Rangatira and the science capability of world renowned scientists from PFR and AGR, creating a confluence of knowledge that will be applied to restoring Mana, and a social licence to operate within the currently exploitative primary production industry. The research team will redesign primary production as a Mosaic of interwoven land use enterprises that deliver social, environmental, cultural and economic wellbeing, starting in the East Cape region, with 150,000ha of Ngati Porou whenua underpinning this production reformat. It will then, over the following 10 years, support industry to adopt the Model and expand it across Aotearoa. The programme reconfigures the supply chain making it ecologically responsive and adaptive to producer needs, consumer preferences and market trends. The provenance story and Brand created via the development of eco-credentials and cultural authenticity will deliver a premium return on current [commodified] primary produce, generating an economic lift in rural Māori communities, then across the sector. This kaupapa Māori research and development programme is an Exemplar. It operationalises Government development objectives and informs new [sustainable] Policy settings.
WSP New Zealand Limited	Sustainable biomass-derived materials to replace bitumen for transport infrastructure	Mr Philip Herrington	5	$9,100,000	An efficient road transport infrastructure underpins successful societies and economies worldwide. Bitumen, a by-product of petroleum refining, is an essential material component of that infrastructure and globally over 100 million tonnes of bitumen are used annually for road construction and industrial applications. There is currently no viable alternative. The price and availability of bitumen is highly dependent on high-volume refining of crude oil for heating and transport fuels. As a response to climate change, global fossil fuel consumption and hence bitumen availability, is forecast to be greatly reduced in the future. This will make petroleum bitumen less and less affordable and threatens NZ's security of supply. Our goal is to convert NZ sustainable forestry and animal biomass products, into a substitute material for petroleum-based bitumen used in road construction, roofing and numerous other industrial applications. Our research is inspired by Ngāi Tūhoe and embodies Māori values and worldview: kaitiakitanga, guardianship and conservation of the land. Using a novel methodology we aim to convert cellulosic materials into a high-performing viscoelastic "biobitumen" made 100% from natural, renewable materials. To be successful the new biobitumen must be economically viable, but also be designed to eliminate the rheological and durability deficiencies inherent to petroleum bitumen. Our programme is designed to address these challenges. We have assembled a strong international research and stakeholder team to ensure scientific excellence and to facilitate efficient uptake and implementation ensuring a wide impact for New Zealand. Our vision is that our research will create a platform to use New Zealand's resources towards a low-emissions circular bioeconomy.

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Organisation	Title	Science Leader(s)	Duration *(years)*	Contract Value *(GST excl)*	Applicant's Public Statement
Te Whare Wananga o Awanuiarangi	*Generation Kāinga: Rangatahi building a regenerative and resilient Aotearoa	Jenny Lee-Morgan	4	$9,778,272	Generation Kāinga addresses one of the most pressing Māori priorities and greatest aspirations: Māori housing tenure and our ability to exercise authority over our kāinga for the well-being of whānau, hapū, iwi and communities. This kaupapa Māori research programme seeks to unlock the capacity of rangatahi Māori to become key agents in promoting and developing whanau housing and kāinga solutions. A Kaupapa Māori approach aligns with a Community Based Participatory Research (CBPR) that centralises the participation and agency of the community, or in this case rangatahi. A strength of this project is the participation of outstanding rangatahi who are emerging researchers and change-making leaders, as well as innovative and successful rangatahi groups and initiatives. Given the holistic nature of kāinga and the complex challenge of transformative change in the Māori housing sector, the multiple dimensions that facilitate a Generation (of rangatahi committed to) Kāinga is expressed in four ORA (wellbeing) themes: Kāinga ora; whenua ora; rangatahi ora; and ōhanga ora. This project is organised to systematically undertake innovative research that will deeply connect with our rangatahi and whānau; reveal innovative rangatahi solutions and pathways to repatriate, restore and create kainga; and mobilise whānau, iwi and hapu, as well as government agencies and service to take action and enact strategic change. This kaupapa Māori project is not only made up exclusively of Māori researchers, but features some of the most eminent Māori research leaders in their respective fields, including Prof Linda Smith, Prof Jenny Lee-Morgan and Rau Hoskins. Our team brings together the wisdom of mātauranga Māori, intersections with western science, expertise in the Māori housing sector, as well as wide professional and community networks through our extensive whanaungatanga relationships.
University of Auckland	*Adapting to climate change through stronger geothermal enterprises	Professor Shane Cronin	5	$6,460,260	Aotearoa hosts world-class geothermal environments suited to low-cost, sustainable energy generation. These could pave the way to an economically achievable (and just) transition to a hydrocarbon-free economy. In order to achieve this sustainable goal, this project will deliver underpinning knowledge that integrates new ecological economic, computational, Mātauranga Māori and geoscience to promote safety, sustainability, and growth of diverse geothermal enterprises in Aotearoa-NZ. We will also demonstrate global leadership to enhance geothermal use around the world. Outputs will include new numerical simulations and geoscience models of geothermal-system stability and background hazards - based on scenarios of geological processes, climate-driven hydrological change, and anthropogenic interventions (including CO2 sequestration and intensification). Growth will be encouraged by the development of new economic models and decision-support tools that quantify the diversity of benefits and losses of different geothermal development options – particularly highlighting wellbeing and targeted needs that help provide better social financial/investment levers. New decision-making frameworks for geothermal investment will integrate new Kaupapa-created Mātauranga Māori values and target Māori-identified wellbeing and skills-development pathways. Using our Aotearoa and international experience, we will work with energy companies, Māori businesses, land trusts, and Government to develop new economic tools that driving new geothermal investment. We will build more appropriate business cases that underpin growth of diverse, sustainable, and productive geothermal enterprises. This will rest on a foundation of new impact-based investment knowledge and tools that highlight the wider benefits from geothermal development, especially to improve regional and Māori economies. Our work will contribute a safe, thriving, expanding geothermal economy. This is critically important, because geothermal systems are the key to low-carbon sustainable energy generation, have diverse direct-use heat applications, and potential for sustainable smart-mineral extraction.
	Reversing Carbon Emissions in the Geothermal Energy Industry: Template for Emission-Intensive Industries	Dr Sadiq Zarrouk	5	$6,034,345	In this project, novel technology will be developed to reduce carbon emissions from geothermal power plants by reinjecting and mineral trapping greenhouse gases back to the geothermal reservoirs where they originally came from. This is in line with the New Zealand government's targets of 95% renewable electricity generation by 2035 and net zero emissions by 2050. While there have been several investigations and projects in New Zealand and overseas to capture and store greenhouse gases deep underground, geothermal power developments provide the best opportunity. This is because the geothermal projects typically capture (but release) the greenhouse gases and have existing reinjection wells for the return of the greenhouse gases back into the deep rock formations. Our technology is based on controlling the chemical reactions between the reinjected gases and the reservoir rock to convert the waste gases into solid form, which will be permanently stored underground. Our programme will play an essential role in unlocking the potential of Māori resources. It will underpin research for the development of 'carbon-negative' energy, economic growth, know-how, and job creation while sustaining the environment. Partnering with New Zealand and the international industry, iwi, and local government will provide the essential understanding and proven applied implementation of greenhouse gas capture and storage in geothermal systems. Underpinning further advances in greenhouse gas disposal and storage from other fixed emission sources. Once proven, our novel technology has the potential to be deployed to other, also more intense greenhouse gas emission sources (e.g., power production, material processing, industrial-scale forestry, and dairy).

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	Shaping a circular market system for plastics in New Zealand	Associate Professor Johan Verbeek	5	$11,713,878	Remaking products from plastic waste presents an opportunity for New Zealand to reduce the $500m p.a. loss from dysfunctional recycling practices, limit the reliance on virgin plastics we import and create new, high-end plastic materials. Additionally, by keeping plastics in a circular loop, ultimately a reduction in plastic leakage into the environment can be achieved, which has significant environmental and social impact for New Zealand and will improve its poor global ranking on solid waste management. However, the barriers to collecting and recycling locally are complex and it is widely accepted that a single solution to the plastics waste problem is unrealistic. Instead, a coordinated approach technological innovations and involvement of all stakeholders in supporting a new marketplace for plastics. Recognising this complexity, our research programme has been co-designed with a multi-disciplinary team of researchers from engineering, strategic marketing and design and a comprehensive set of stakeholders from New Zealand's plastic industry. Over the next five years, we will develop innovative technologies to reform currently unused plastic waste into upcycled high-end plastic material that can be used for industrial production. For these technologies and materials to be successfully commercialized, we will create a marketplace for plastics and design digital tools (system infrastructure and user interfaces applications) to ensure individuals, communities, start-ups and organisations have the knowledge and access to access the marketplace.
University of Canterbury	*Pūhiko Nukutū: a green hydrogen geostorage battery in Taranaki	Andy Nicol	5	$11,837,090	Aotearoa New Zealand's economy and energy system is undergoing a fundamental transformation to achieve climate change and decarbonisation goals. Pūhiko Nukutū (Earth Battery) is investigating how to create large stores of green hydrogen underground earth batteries that can unlock a potentially massive hydrogen industry in Aotearoa. The ability to store hydrogen, in large quantities and for a long time, means that it can be produced when electricity costs are low, and later sold when prices are high, or when it is strategically valuable, for instance, when hydro-dams are low. The cultural, environmental and social acceptability of Pūhiko Nukutū is also being investigated to ensure that decision making is fully informed by both science and mātauranga Māori as integral parts of the holistic impact analysis. This will be essential to progress from innovation to implementation. Pūhiko Nukutū examines the complex interactions of rocks and microbes when exposed to hydrogen, to predict how, where and for how long hydrogen can be stored. The international exemplar Mauri Model Decision Making Framework is the basis for representing and analysing the holistic impacts upon mauri. We will use geophysical investigations, computer models, and systems thinking to evaluate how different storage approaches impact the mauri (life-supporting capacity) of communities, Iwi and the environment. Finally, we will study how this new technology can integrate symbiotically with New Zealand's complex energy system. Our programme will include contributions from scientists, Iwi experts, and industry leaders across Aotearoa. Through our international partners, we have access to cutting edge laboratory and computing facilities. Supported by a well-positioned, transitioning energy sector, hydrogen geostorage has the potential to unlock a multi-billion dollar hydrogen economy that benefits all of New Zealand.
University of Otago	Housing children and youth: Ensuring Aotearoa's future get the best start possible	Associate Professor Nevil Pierse	5	$5,837,561	No place is more important to children and youth than their home. Yet, each night in Aotearoa, more than 7,000 young people experience homelessness. A similar number of children are separated from their parents because of severe housing deprivation and over 400,000 are in housing supported by the government. However, Aotearoa's housing support systems are focused on adults. The effect of inadequate housing on tamariki and rangatahi and their experiences within the housing support system are poorly understood. Family disconnection due to housing instability is detrimental to belonging and whanaungatanga. Supportive relationships with parents, whānau, and the wider community are important protective factors for children and young people. The voices of children and young people must be heard and their stories understood to address their housing needs effectively. Currently, there is a gap in the research for how the housing support system can best ensure the wellbeing of young people so that they are set on pathways to future prosperity and success as adults. This programme will create evidence to support the development and realisation of housing support systems that improve outcomes for tamariki and rangatahi. This programme brings together world-leading experts on housing, communities, big data and children, and young people. We will explore the multi-faceted topic of the housing support system, which will be the first time such comprehensive research has been conducted on the topic in Aotearoa. This evidence will be used to innovate and implement a new, equitable housing support system grounded in Te Tiriti o Waitangi that provides holistic, long-term outcomes for children and youth.

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University of Waikato	Pou rāhui, pou tikanga, pou oranga: reigniting the mauri of Tīkapa Moana and Te Moananui-ā-Toi	Kura Paul-Burke	5	$13,950,715	This project is a true representation of iwi-led direction, visioning and action for Tikapa Moana/ Te-Moananui-ō-Toi. It is constructed and written by iwi members with advice and guidance provided by a korowai (sheltering cloak) of Māori academics actively supporting the project to fruition. This is mātauranga Māori in practice. Iwi-led not academic led, representing a normalised Māori approach to action. This project is an exemplar of new ways of approaching, actioning and normalising mātauranga-led research for the benefits of iwi, their wider communities and Aotearoa New Zealand. The collaborative project brings together five iwi (Ngāti Pāoa, Ngāti Tamaterā, Ngāi Tai ki Tāmaki, Ngāti Hei and Ngāti Rehua Ngāti Wai) that have implemented rahui (temporary legislative closures for identified species and spaces) in the degraded waters of Tikapa Moana/ Te Moananui-ā-Toi. This intergenerational project will be a co-production across iwi experiencing similar catastrophic impacts in the moana to embark on innovative, replicable, pragmatic, in-water, mātauranga Māori solutions and actions to assist the regeneration and restoration of rohe moana. In Aotearoa New Zealand, there is an increasing demand to investigate alternative ways of accessing, engaging and implementing mātauranga Māori to better understand degradation (e.g., declining populations, sedimentation, climate change, predation) and assist restoration initiatives (e.g., marine cultural monitoring, restorative aquaculture, bio-waste alternatives to plastic, technological tools) for culturally and ecologically important marine taonga species and spaces into the future. This project will deliver new solutions for restoring and managing rohe moana and kaimoana for present and future generations.
	Toka ākau toitu Kaitiakitanga – building a sustainable future for coastal reef ecosystems	Professor Chris Battershill	5	$8,809,570	Rocky reefs characterised by kelp are critical to biodiversity and functioning of New Zealand's coastal ecosystems. Their lynchpin role in cultural, recreational and economic activities in the 'blue economy' is undisputed, but they are under serious threat, deteriorating from cumulative land and marine stressors. Fine sediments from catchments smother the benthos and darken coastal waters, shallowing the compensation point for kelp, diminishing recruitment of key species, and contracting suitable habitat. Reductions in productivity, alterations in nutrient flux and biogeochemistry of neritic waters result in trophic disruption and degradation of rocky reef infrastructure. The problem is urgent and embedded within a fast-changing climate. Mana whenua, as kaitiaki, and society are demanding better management and tools to address these issues; the resources to understand causes and consequences at relevant scales are currently absent. We will deliver novel science and high-tech tools, combining e-DNA, remotely-sensed biophysical surveillance, acoustic technologies, environmental chemistry, and ecological testing to delineate effects and responses to manageable stressors. Understanding present-day departures of ecosystem health from historic baselines will inform approaches for tracking reef condition. This is achieved through co-design and partnership with mana whenua, an outstanding team of researchers, and established relationships with management agencies mandated to monitor, improve and report on the coastal environment. Together, we aim to reverse reef degradation by formulating an adaptive strategy and toolbox targeting manageable stressors, in-situ testing of scaled-ecosystem drivers, optimisation of tools for addressing degradation, and ground-truthing management options in real-time. Our base is Mātauranga Māori where knowledge of catchment condition is linked to coastal health and provides restorative targets. Our research spans catchments in four oceanographic regions and harnesses a mātauranga-science approach. Our partnership ensures uptake-into-practice of mitigation measures developed.
Victoria University of Wellington	*Greater Electricity Generation and Industrial Heat Opportunities from Existing and Greenfields Geothermal Resources	Professor James (Jim) Johnston	5	$6,346,490	Geothermal energy is an important natural, sustainable, low carbon resource for generating electricity in NZ. We have discovered a transformational chemical and engineering technology (CaSil technology), to recover 60-100% more heat energy for electricity generation and industry/consumer direct heating applications, from hot separated water flows in existing and new geothermal plants. We achieve this by solving the major worldwide problem of silica deposition as an intractable sinter from the hot water in geothermal resource utilisation, which blocks pipework, heat exchangers and reinjection wells, severely limiting the amount of heat energy that can be extracted and electricity generated by the binary cycle technology. Our innovative technology captures and rapidly transforms silica in geothermal water into a unique nanostructured calcium silicate (CaSil) material before silica deposition takes place. The CaSil does not adhere to metal surfaces and is separated as a useful product for environmentally beneficial and water restoration applications. We will use the CaSil product to manufacture CaSil-based controlled-release fertilisers, providing more effective fertiliser use and reducing excess nutrient run-off and pollution of waterways. Our research will deliver a transformational technology that successfully addresses Climate Change mitigation and Clean Water restoration. New revenue streams will be generated from the additional electricity generated, reduced eothermal field and equipment maintenance, and from CaSil fertilisers. The technology is applicable to New Zealand and international geothermal resource utilisation for electricity generation.

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	Our changing coast – Sea-level rise on Aotearoa's dynamic margin	Professor Tim Naish	5	$12,994,020	We know the sea around Aotearoa is rising and that our coastal communities must adapt, but we do not yet know enough about how our coastal regions will be affected by sea-level rise (SLR) to ensure our adaptation measures are effective and appropriate. We do not yet know how hazards will evolve and shift risk along our >15,000 km of highly variable coastline. Addressing these critical knowledge gaps, requires coordinated effort between Iwi, Māori, researchers, government agencies, private sector, and community groups. Te Ao Hurihuri: Te Ao Hou, Our Changing Coast (OCC) programme offers novel insight into our evolving coastal system and prepares planners, decision makers, and communities to address our coastal adaptation challenge. OCC directly supports New Zealand's Climate Change Amendment Act and Climate Change Commission's advice regarding pathways for a just transition to a low carbon economy by 2050. Our research interweaves threads of mātauranga-a-Māori, mātauranga-a-pūtaiao, and other science knowledge. Ka mua, ka muri: although we walk into the future our eyes remain on the past. We utilise knowledge from our past and the latest datasets and models to develop (1) a new suite of "state of the art" SLR projections, (2) tools to identify evolving coastal hazards, and (3) tools and decision-making procedures that manage risk, limit social disruption, and enhance equitable, sustainable, and healthier communities. By the end of our programme we aim to ensure that New Zealanders are using the best scientific knowledge and evidence to effectively anticipate sea-level rise and its impacts, in order to develop and implement sustainable adaptation and management approaches guided by mātauranga Māori.

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