Generating Recommendations for a Microfabrication Cluster in New Zealand

Submitted By:
John Lomi
Rachel Ooyama-Searls
Tyler DeFosse
William Boyd
microfab@wpi.edu

Project Advisors:
Prof. Beth Eddy, WPI
Prof. Bob Kinicki, WPI

Sponsored By:
Callaghan Innovation

Table of Contents

Table of Figures

Chapter 1: Introduction

All over the world, technological industries are developing as a result of innovative progress made in scientific fields of study. Links between research facilities and manufacturers form economic clusters, strengthening the potential of any industry's success as the world becomes more connected through the Internet. In New Zealand, the microfabrication industry is starting to emerge and grow. However, keeping industry inside the country can be difficult. Creating a cluster of manufacturing and research organizations, connected geographically and through technology, will strengthen the industry in New Zealand.

The global microfabrication industry is still a relatively new and emerging field, especially in New Zealand. Due to its small population, New Zealand has faced the problem of losing industries to other markets in other countries with greater resources. Callaghan Innovation, a government organization focusing on using technology to promote New Zealand business, wants to establish a microfabrication cluster in New Zealand to keep the industry in the country thus breaking this trend. In the past, there have been other successful industry cluster initiatives in New Zealand, such as the MAREX boat-building cluster. There are several companies and institutions in New Zealand that have the potential to become part of a cluster as seen in Figure 1, but not all of these organizations are active in the cluster initiative.

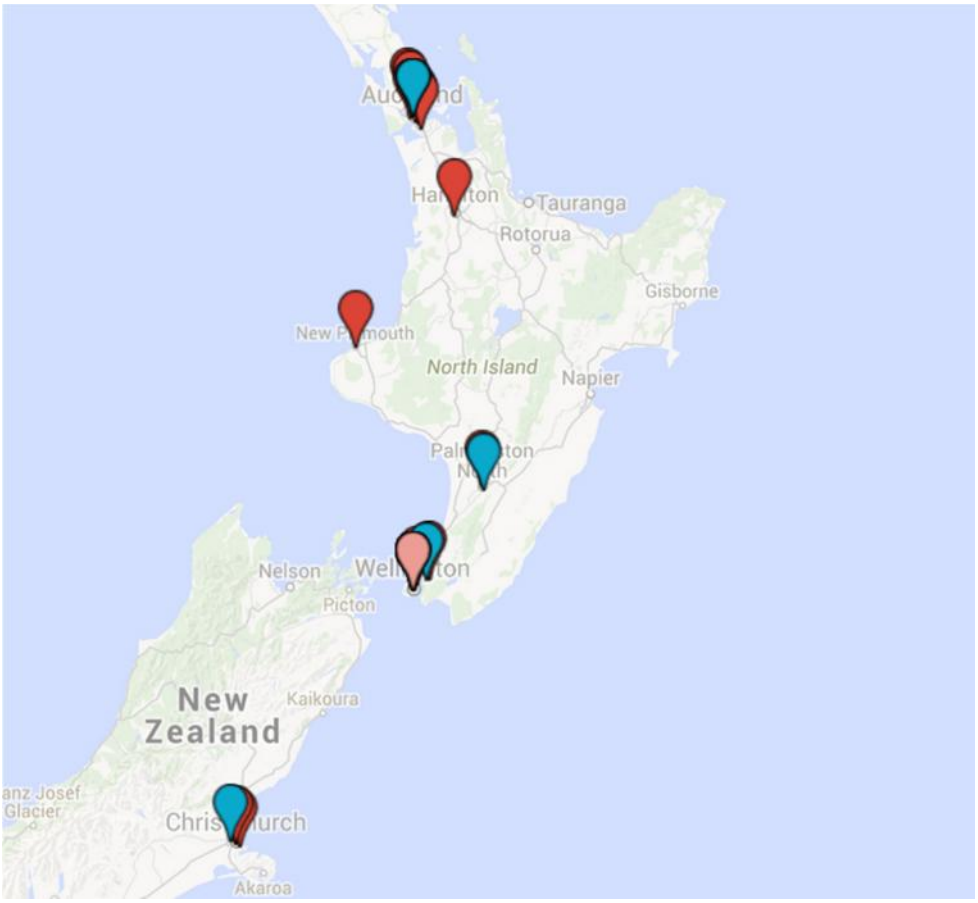

Figure 1: Map of current Organizations

In order to establish a cluster, the different organizations and sectors involved must establish a community of trust, sharing, and communication. In places where clusters form, there tends to be a higher quality of life as this attracts more skilled laborers. One way that the government can help establish a cluster is to set up incubator programs which help startup companies form without the risk of failure. These incubators can provide startups with physical space and capital. To find out which of these elements already exist in the microfabrication industry in New Zealand and how we can generate our recommendations for further growth, we will focus our research on various companies, research institutions, and other related organizations in New Zealand.

In order to facilitate the emergence of a successful microfabrication cluster, we need to evaluate the views and opinions of New Zealand experts in the field and non-expert citizens as these will be the people who make up and support the industry. Understanding the technical aspects of creating a cluster, as well as the effects such a cluster will have on New Zealand's environment and culture, are key to the success of this project. We will specifically focus on the concerns of the Maori as they have not been generally involved in technological fields. The largest portion of the project is to evaluate opinions and needs of a variety of different stakeholders through interviews and surveys. We will use this data to establish a set of recommendations for how each stakeholder should proceed in order to initiate the formation of a successful microfabrication cluster. Some major concerns that we will address in the survey and interview questions are environmental effects of the industry, cultural conflicts with industry practices, government regulations regarding clusters, and interest level of the company or institution in becoming part of the cluster. The team will use this information to create recommendations for Callaghan Innovation regarding the formation of a microfabrication cluster.

Chapter 2: Background

Microfabrication is the creation of devices including actuators and sensors on the scale of 1 micrometer to 1 millimeter. The products of microfabrication are referred to as microelectromechanical systems, or MEMS. These systems consist of structures, actuators, electronics, and sensors and are used in a variety of applications (MEMS & Nanotechnology Exchange). Chemical etching and high aspect ratio lithography are both ways to create a micro device. High aspect ratio lithography is where UV light is shone through a photoresist, a material designed to act similarly to a camera film negative, to create a pattern on a silicon wafer (MicroChem, 2015).

The microfabrication industry in New Zealand is based around one overarching institute called the MacDiarmid Institute for Advanced Materials and Nanotechnology in Wellington. This institute is a research center that works closely with suppliers, industrial companies, and other research institutions in order to make advancements in this technology. This chain of companies and institutions have the opportunity to form a cluster which would be beneficial for the New Zealand economy and for the future of the microfabrication industry. One government organization that is actively trying to develop this microfabrication cluster in New Zealand is Callaghan Innovation.

2.1 Cluster Theory

Clusters are groups of interconnected organizations associated to a particular field or industry. These organizations are made up of companies and firms, specialized suppliers, associated research institutions, universities, and service providers (MassTech, 2015). Alongside the geographic proximity that characterizes clusters is the sharing of common resources. Knowledge, infrastructure, growth opportunities, and also barriers to growth are all explicitly and implicitly shared among the different organizations that constitute a cluster. As one firm succeeds,

another will copy them and reap the benefits. However, if one company fails, there is a strong chance that more will follow.

2.1.1 Formation and Sustainment of Hotspots

Valerie Lindsay, from the School of Marketing and International Business, in the Victoria University of Wellington, uses the Marine Export Group (MAREX), an export-based New Zealand boat building cluster, as a means of exploring the formation and evolution of high-performing industries. The study she performed on MAREX suggests that the reason for the formation of industry clusters is the belief that the benefit of being in a cluster increases as more organizations enter (Lindsay, 2005). There is one specific type of cluster categorized as a "hotspot." Inside these hotspots exists rapid economic growth, often with the focus on technology. The firms comprising these clusters are competitive and highly innovative with distinct identities. However, with this rapid growth of clusters comes a trend of decline in the absorptive capacity of the individual firms and of the cluster (Lindsay, 2005).

The absorptive capacity of a firm is the way it gathers and uses knowledge from outside the firm. It is this attribute of hotspots that ultimately leads to the failure of the cluster. Access to and application of new information provides the innovation and adaptation potential that a firm needs to survive. In declining hotspots, there is an encompassing reduction in firms' adaptive capacity. The adaptive capacity of a firm represents how the firm reacts to unexpected situations and new technology, as opposed to absorptive capacity which represents how a firm gathers and uses new information. This reduced adaptive capacity results in limited new knowledge, which in turn hinders the innovative processes that sustains firms in these high-growth industries (Lindsay, 2005).

In order for firms in these hotspot clusters to sustain themselves, they need to prevent themselves from falling into a competency trap. This is where a firm tends to plateau in terms of innovation and growth. When companies rely too much on internal processes and ingnore

external input, the firm cannot recognize new opportunities. This contrasts with the coevolutionary view which is using both inside and outside sources for expansion (Lindsay, 2005).

2.1.2 MAREX: A New Zealand Hotspot

In the late 20th century, New Zealand's boat-building industry, similar to today's microfabrication industry, was an emerging industry. As an industry, there was good demand for its products, with 50% of New Zealanders enjoying boating and 30% fishing, but the core components of a strong industry were lacking. Several factors that shaped the growth of the industry include an extensive coastline, favorable climate, university research, and international competition.

The boat-building industry in New Zealand employs 8000 people in over 1300 companies. MAREX consists of about 175 of those companies, specializing in the construction of superyachts and racing yachts. As of 2005, MAREX experienced a growth of 25% per year for five years, classifying it as a hotspot. Even with the small percentage of firms within the boat-building industry, it accounts for a large portion of New Zealand's marine industry's annual sales (Lindsay, 2005).

The aforementioned problem with hotspots is that a trend of high growth leads to individual firms entering competency traps ultimately leading to market decline of the individual firms and the industry. MAREX avoids this problem by using both internal and external sources of information. This diversity is the reason behind the constant stream of new knowledge. MAREX includes firms who specialize in clothing, cabinet making, communication, engines, sails, and spars, in addition to the core boat-building firms (Lindsay, 2005).

The microfabrication industry can learn from the MAREX cluster. For the boat-building industry, the University of Auckland has a Yacht Research Unit, and for the microfabrication industry, the University of Auckland has the Auckland Microfabrication Research Facility. Similarly to the demand for boats in New Zealand, the demand for microfabrication is rising with the

demand for smaller technologies around the world. To help stimulate the growth of the microfabrication industry, there is also international competition for microfabrication.

2.2 The Microfabrication Industry in Massachusetts

Massachusetts is home to many microfabrication companies and research groups and is a great model for New Zealand. There are companies like MicroChem and Analog Devices that supply and manufacture devices. Institutions such as the Massachusetts Institute of Technology (MIT) and Draper Laboratories conduct research in the industry as well. Because of the presence microfabrication has in Massachusetts, the state has the potential to be a good model for the industry in New Zealand.

2.2.1 Key Firms in Massachusetts

MicroChem creates photoresists and other MEMS materials and products. They have many supporting companies, like Dow Chemical and Advanced Packaging Technology, whose products they use and distribute. MicroChem acts as a supplier of chemicals used in multiple microfabrication processes and plays a key role in the self-sustaining cluster of microfabrication companies in Massachusetts. This company was one of the first of its kind in Massachusetts and therefore has established its role and importance in the industry (MicroChem, 2015).

Another company that plays a big part in the microfabrication cluster of Massachusetts is Analog Devices. This company manufactures MEMS products and devices. They focus on accelerometers, gyroscopes, and other movement tracking devices. This company is a manufacturer whose products are the result of the microfabrication cluster (Analog Devices, 2015).

2.2.2 Key Research Organizations in Massachusetts

The Massachusetts Institute of Technology is involved in nanotechnology research. MIT has a research lab called the Center for Polymer Microfabrication, or CPM, that focuses on

microfluidic technology, which performs laboratory functions on a microscale. For example, a microfluidic device can measure proteins in a sample or test the effectiveness of an antibiotic. Furthermore, this group works to develop large-scale manufacturing and commercialization of these fluidic devices, a key issue that the project will address in New Zealand. Their commercialization research includes cost analysis, equipment, quality, and logistics of manufacturing. CPM studies supply chain influences on products as well as maintaining or changing these relationships through the product's life cycle. Their research is similar to the goal of this project (CPM).

Draper Laboratories is a not-for-profit research and development company that deals with microfabrication applications. The microfabrication research done at Draper is separated into three categories: tissue engineering, deep brain stimulation, and organ assistance using microfluidic devices (Draper, 2015). The research done here helps the cluster grow and find new markets and applications. A microfabrication cluster in New Zealand will also need a research and development sector to keep the industry fresh and thriving.

2.2.3 Other Key Organizations in Massachusetts

The cluster in Massachusetts doesn't contain just industrial and research components however. The cluster includes consultants like Innovare, marketing firms like Questex Media, software and integration companies like Sensata Technologies, and equipment manufacturers like ULVAC.

In addition, there are government based organizations like the Massachusetts Technology Transfer Center, or MTTC, which aid in the formation and upkeep of the cluster. The MTTC helps create a bridge between research facilities and their respective industry. Additionally, the MTTC works to develop new and existing companies through leadership training and economic support (Massachusetts Technology Transfer Center, 2015).

2.3 The Manufacturing Sector in New Zealand

2.3.1 Economic Overview of New Zealand

The New Zealand economy has been through dramatic changes in the past three decades including changes in its government regulations, recent disasters including the devastating Canterbury earthquakes from 2010 to 2011(McSeveney, 2014), and the effects of the global financial crisis in 2008. However, New Zealand has managed to maintain a steady recovery in response to its most recent struggles. The New Zealand Treasury released an economic and financial overview in 2015 discussing their recovery and their economic outlook (The Treasury, 2015).

Through reductions in government regulations, in the OECD (Organisation for Economic Co-operation and Development), New Zealand has changed from one of the most regulated to one of the least regulated countries. The government has imposed regulations that allow firms and companies to make more independent decisions about how they want to proceed. This will allow the microfabrication industry to grow and adapt to any changes more easily. The current government hopes to continue strengthening the New Zealand economy through key policy points such as rebuilding Christchurch (The Treasury, 2015).

In response to the global financial crisis, the government tried to restore the lost confidence in the economy by helping the banking sector, individuals, and businesses. To help the banking sector, the government set in place retail and wholesale bank guarantees. They also incorporated cuts in the income tax as well as relief packages for small and medium-sized companies to assist individuals and businesses. The Canterbury earthquakes of February 2011 slowed this recovery. However, the recovery is seen as a source of growth through residential, commercial, and infrastructure investments.

2.3.2 Manufacturing in New Zealand's Economy

A major problem facing the manufacturing sector in New Zealand is the exchange rate of the New Zealand dollar. The IMF (International Monetary Fund) suggested in 2012 that the New Zealand dollar was 10-20 percent overvalued (Wheeler, 2013). Governor Graeme Wheeler stated in a speech addressing the New Zealand Manufacturers and Exporters Association in Auckland that along with the issue of overvaluing the New Zealand dollar, there are other components such as globalization, outsourcing, international supply chains, and the competition between low cost producers that are hurting the state of the industry (Wheeler, 2013).

The lack of skilled labor and the current architecture of the manufacturing sector makes the creation of a sustainable microfabrication cluster in New Zealand difficult. In order to shed light on the situation, Castalia, an advising company, created a report for BusinessNZ on the dynamics and competitiveness of New Zealand and its manufacturing sector (Castalia, 2014). In their report, Castalia conducted a study involving 15 manufacturing companies showing high growth to ascertain what would determine strong growth in the future. A couple of the main issues that Castalia highlights in this study are the architecture of the industry and the shortage in skilled labor.

2.3.3 Sector Architecture

The focus of the manufacturing industry in NZ has shifted from manufacturing to a mix of manufacturing and services including research, design, and marketing. This shift has caused some misunderstandings about the sector's composition and, consequently, its strategies for sustainable growth. Using official government statistics, Castalia concluded that there are misconceptions on the classification of specific units (Castalia, 2014). In particular, many products and services that New Zealanders classify as in the services sector are in fact a part of a vertically integrated business in the manufacturing sector. In other words, the firms that are distributing these services are also the ones who distribute the services. Instead of having a separate firm

handle the service, the firm handles it internally. This adds to the labor shortage problem due to added confusion on the role of manufacturing in New Zealand. Castalia determined that the common factors that made the firms in the cluster successful are talent-driven innovation instead of a cost-minimization approach and a vertically-integrated architecture. The success of these individual firms then in turn would make a successful and competitive manufacturing sector in New Zealand.

2.3.4 Skilled Labor Supply

The lack of skilled labor in the manufacturing sector is a problem hiding in the shadows of the economic success of the industry in New Zealand, but it will become more of an issue the longer companies and institutions ignore it (Castalia, 2014). Castalia stated that the industry was made up of 191,000 jobs by the middle of 2013 and was supplying 14.6% of the country's GDP in 2012. This makes it one of the four largest sources of jobs and income in New Zealand, establishing New Zealand as more manufacturing-heavy than its neighbor, Australia. Culturally, this is an issue, as many citizens do not view themselves as a nation that relies on manufacturing. This leads to many people not choosing a manufacturing career path. The survey conducted by Castalia targeting high-growth manufacturing firms determined that the lack of skilled labor is the highest of concern in the industry.

2.4 Microfabrication Applications in other New Zealand Industries

It is important for the microfabrication industry in New Zealand to make connections with already established industries in the country in order for it to be able to grow and expand. Some examples include the agricultural industry, the medical industry, the environmental industry, and the Internet of Things.

2.4.1 Agricultural Applications

Agriculture is one of the largest industries in New Zealand and is directly responsible for 5.0% of GDP (Treasury, 2012) and approximately 50% of total income from exports comes from meat, dairy, and wool products (Productsfromnz.com, 2015). It follows that for the microfabrication industry in New Zealand to be successful, it must make efforts to connect the two industries.

The dairy industry accounts for 39.1% of agriculture in New Zealand and MEMS can be applied heavily in this area (Treasury, 2012). One such application is a device, seen in Figure 2, that can detect and immobilize pathogens including E.coli, Streptococcus, and Staphylococcus in milk in real-time (Smith & Gottfried, 2015). This is incredibly useful, not only to ensure the quality of milk, but also because it can lead to early detection of diseases such as mastitis in dairy cows. Mastitis is an inflammation in mammary tissue and is a financial issue in dairy industries worldwide, costing the U.S. one billion dollars annually (Smith & Gottfried, 2015).

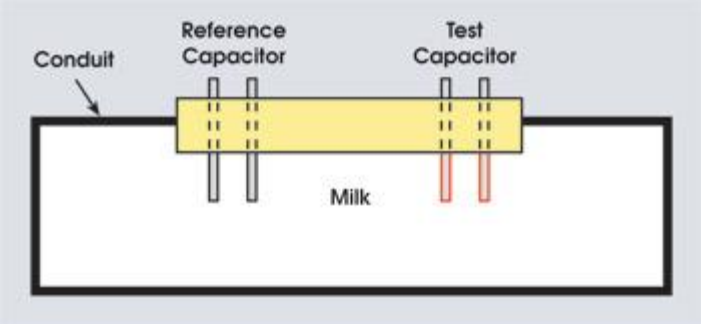

Figure 2: Sensor in milk conduit (Smith, 2012)

SpectralSight Inc. also developed a micro-fabricated device that is applicable in the agricultural industry. This device utilizes hyper-spectral imaging to detect problems in crops and food. By tuning the device to specific light frequencies, users can detect fungal infections and needs for irrigation (Smith & Gottfried, 2015). Users can also utilize this type of device for food that is already packaged and being sold on shelves (Smith & Gottfried, 2015). Detecting these issues helps to optimize both production and quality of the food.

2.4.2 Medical Applications

There are several ways that microfabricated technology applies to the medical field and some include biosensors and micropatterning. Two specific biosensors that could be important to New Zealand healthcare are continuous glucose monitoring sensors (Huang, 2014) and heart failure monitoring sensors (Sjm.com, 2015).

Diabetes is the fastest growing health problem in New Zealand with over 240,000 people diagnosed with the disease (Ministry of Health NZ, 2015). Glucose monitoring sensors are the main tool diabetics employ to keep track of and control their blood sugar. The Department of Mechanical Engineering at Columbia University has developed a fully implantable MEMS dielectric affinity glucose biosensor. This biosensor is capacitor based and is able to monitor blood glucose concentrations in real-time (Huang, 2014).

Heart disease is the leading cause of death in New Zealand, resulting in 30% of deaths annually (Heartfoundation.org.nz, 2015). Devices that help in this area of the medical field are helpful to the general health of New Zealand. St. Jude Medical has developed what they call the CardioMEMS™ HF System which is a tool for early detection of heart failure. The device is able to do this by monitoring the pulmonary artery pressure with an implanted sensor. This device, as seen in Figure 3, has reduced heart failure related hospitalizations by 43% in clinical trials (Sjm.com, 2015).

Figure 3: Heart Failure Monitor System (CardioMEMS HF, 2015)

Another medical application is in research using microfabrication techniques. Technicians currently use micropatterning methods to fabricate the extracellular environment for cancer cells to grow in (Yang et al., 2015). This aids in arrangement, proliferations, and cell behavior research which is important to understanding how cancers form and respond in the body (Yang et al., 2015). Scientists are performing cancer research all around the world including in New Zealand.

2.4.3 Environmental Protection Applications

While environmental protection is not a typical industry, it does have many microfabrication applications and is fundamentally important as it deals with the safety of the environment. There are several sources citing the potential of using micro-sensors to monitor environmental conditions to detect pollutants (Suzuki, 2000) (Zou, Z. et al., 2007) (Feeney & Kounaves, 2000). The environmental protection industry can save money by switching over to microfabricated devices instead of using their macro counterparts. This is due to batch-fabrication, which allows lab personnel to make more sensors at once, and multi-analyte detection which means that one device can detect and analyze several different molecules or pollutants.

The University of Cincinnati has microfabricated a disposable heavy-metal ion sensor as seen in Figure 4. Researchers can use this sensor at the site being analyzed (Zou, Z. et al., 2007) meaning samples do not need to be taken off-site to a lab. This is not only more convenient, but also much more time efficient. The device is able to accurately detect harmful materials such as lead ions in the soil and in water sources without producing toxic chemicals in the process (Zou, Z. et al., 2007). This is important because the ultimate goal of using these sensors is to help decrease the amounts of pollutants in the environment.

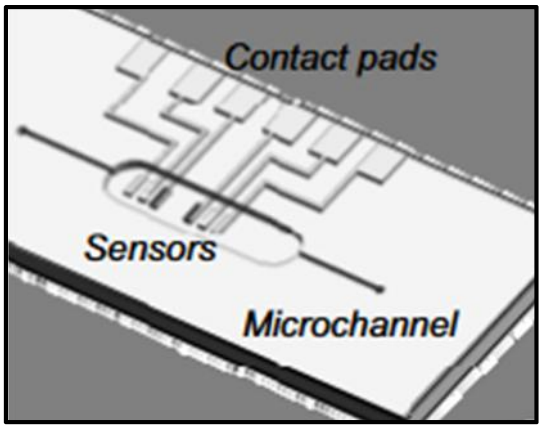

Figure 4: Heavy-metal ion sensor (Bishop, 2007)

2.4.4 Internet of Things

The Internet of Things (IoT) is the concept of multiple items, or things, that consist of embedded systems and an Internet connection. This technology allows objects in the physical world to sense and send data to each other in order to create an efficient, technology-driven environment. Embarcadero Technologies, an American software development company, conducted a survey indicating that the IoT will become increasingly important in the near future. This survey states that 16% of companies working on IoT projects will have their product ready for business in 2014, while for 2015, a projected 62% of companies will have their product ready. Additionally, this survey states that 84% of IoT projects in New Zealand and Australia will be in active development in 2015. These companies are starting to make IoT solutions for other businesses as 92% of IoT developers are working to create a product to be sold in the business market (Henderson, 2015).

Obviously, the Internet of Things is a growing market and MEMS technologies are at the core of a majority of IoT devices. Because this industry is growing and relies so heavily on MEMS technology, it will serve as a great application for microfabrication. Companies that manufacture MEMS technology in a microfabrication cluster will benefit and grow due to the demand for IoT devices.

2.5 Important Factors Shaping the Emerging Microfabrication Industry in New Zealand

The MacDiarmid Institute for Advanced Materials and Nanotechnology is the main research institute for microfabrication in New Zealand; it is a public institute surrounded by branching institutions and companies known as Crown Entities. There are eight of these entities and the MacDiarmid Institute instigated their formation in the last decade or so. This institute propelled the research on microfluidics and nanotechnology so that other companies such as Callaghan Innovation could carry on with specific research to fulfill a desired purpose.

2.5.1 Crown Entities of the MacDiarmid Institute

Callaghan Innovation and other similar companies work together with the MacDiarmid Institute on nanotechnology research as well as industrial applications of this research. Some colleges such as the University of Auckland and the University of Canterbury are crucial contributors to this effort as well. The latter was involved in the creation and commercialization of self-assembling nanowires, working heavily with the MacDiarmid Institute.

Callaghan Innovation is a technology oriented company which pledges to take the ideas of researchers and make them industrially possible. This is one of the most prominent New Zealand companies containing researchers in the field of microfabrication. These researchers have made great progress in recent years in trying to improve the microfabrication industry in New Zealand; Callaghan Innovation is currently at the forefront of the industry.

An article in the journal Smart Materials and Structures contains a step-by-step process in which Andrea Bubendorfer and two other researchers from Callaghan Innovation used microfluidic devices to fabricate microchannels and seal them to a substrate. Demonstrating the ability to produce microstructures and make use of them is the first step for companies trying to break into the microfabrication industry. The second step is figuring out how to lower the cost of

production and manage changing technologies, something Callaghan Innovation is focusing on now (Bubendorfer, 2007).

Another Crown Entity that works closely with the MacDiarmid Institute is the University of Auckland. It has an entire facility dedicated to research on microfabrication for both academia and industry. The students at the University of Auckland Microfabrication Facility complete projects dealing with single cell microfluidics, drug delivery and biosensing actuators, gas sensors, and sensors for sound waves. These projects are important because they allow University of Auckland students to become proficient in all sorts of microfabrication processes and this prepares them to begin working in the microfabrication industry once they've finished university. In fact, microfabrication consulting is an integral part of the academia-industry relationship that the University of Auckland tries to keep intact (University of Auckland).

This research is not simply for the university itself, however. It is also helpful for the growing microfabrication industry in New Zealand. For example, companies in this industry have already used the University of Auckland's facilities "to improve processing conditions for biomedical and industrial polymers, for the design of flowcells for dairy waste stream sensors, and to explore new concepts in gas sensor design." (University of Auckland) The University of Auckland Microfabrication Facility and similar facilities will be important as the microfabrication industry in New Zealand grows as they are institutions crucial for researching efficiency and conditions for various microfabrication processes and products.

2.5.2 MacDiarmid Institute Strategic Plan

Not only is the MacDiarmid Institute making technological progress, it is striding towards social and cultural progress in terms of increasing public acceptance of industry. One way it is accomplishing this feat is by conducting social research with the general public about their opinions on nanotechnology and related fields. This research found "that the New Zealand public generally views nanotechnology favourably, but that there is some aversion to products where

people can be directly exposed to nanoparticles." (Callaghan, 2009) Industry leaders must consider beliefs of the general public regarding microfabrication if the industry is to thrive in New Zealand. This is because if the public does not view the industry favorably, it will receive negative media attention and citizens will be less likely to buy or use nanotechnology products, let alone pursue careers in microfabrication.

In the next six years, the MacDiarmid Institute expects to make significant progress in three areas: increasing the potential for technological advancement and human capital, positively influencing New Zealand's economy, and generating changes in society that increase favorability of microfabrication and the desire to explore a career in such a field (Yewdall, 2015). One of the technique to inspire change in New Zealand society is by interacting with specific groups of people who may not be initially interested in microfabrication. The MacDiarmid Institute has identified these groups of people as the Maori and Pasifika, and a crucial part of the aforementioned six-year plan deals with attempting to integrate these groups into the industry. The plan is to "Develop, grow and formalise relationships with Māori communities founded on mutual exploration of education and business opportunities supported by a science foundation." (Yewdall, 2015: 4) The institute recognizes that the Maori are not necessarily going to be interested in the microfabrication industry due to their beliefs; however, Yewdall believes it is essential that the institute educates the Maori and Pasifika about career opportunities and reasons why the microfabrication industry is beneficial. To achieve this, the MacDiarmid Institute will instill scientific development programs in predominantly Māori and Pasifika schools (Yewdall, 2015).

From the industry's perspective, the best-case scenario would result in the MacDiarmid Institute and the Maori coming to a mutual agreement and more Maori becoming involved in this industry. This would naturally increase the potential for innovation as many fresh, young minds would be diving into unexplored areas of research. The major benefit of getting Maori involved in microfabrication, however, is that it would reduce the amount of foreign workers necessary to keep the industry thriving. The lack of skilled labor is a major problem surrounding the

microfabrication industry, but it could be mitigated with a large addition of Maori or Pasifika people to this field.

2.6 Maori Involvement in the Microfabrication Industry

The overall long-term goal of this project is to develop recommendations for the formation of a microfabrication cluster in New Zealand. This would involve a collection of companies and institutions working together to make technological progress in the microfabrication field. If enough organizations become involved in this cluster, a major issue will be the lack of skilled labor available in New Zealand. Companies can address this problem by importing skilled laborers from other countries, but this is expensive and time consuming. The other option would be to convince more people within the country to work in this industry. A potential pool of labor in this case would be the Maori, but it is uncertain whether many Maori would be willing to work in this field. This is why it is crucial to evaluate the views of the Maori as a stakeholder group before pushing them to do something that potentially conflicts with their beliefs. Generally, the Maori people in New Zealand have not been involved with technical companies and there are very few Maori who hold high-tech job positions throughout the country as shown in Figure 5. Since Maori make up 15.4% of the country's population (Bascand, 2012), it would be beneficial to the future of these industries if they became involved in technology based careers.

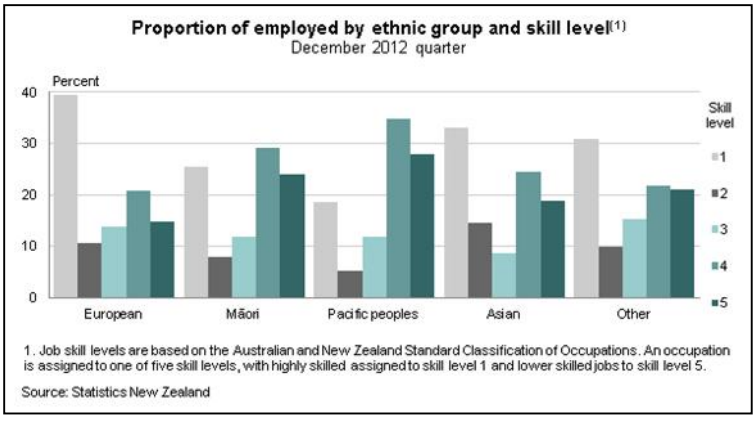

Figure 5: Proportion of employed by ethnic group and skill level (Griffiths, 2013)

2.6.1 Getting Maori Involved with Microfabrication

One strategy to ensure the success of the microfabrication industry in New Zealand is to reach out to the young Maori people and try to convince them that this industry is important for the future of New Zealand. This is crucial because the median age of Maori in New Zealand (23.2 years) is much lower than the median age of the overall population (37.0 years) based on 2012 statistics (Bascand, 2012).

New Zealanders who are involved with microfabrication or similar technology-based industries realize that the lack of skilled labor is a problem that they must address sooner rather than later. The only ways to do this are to either import skilled laborers from other countries or to convince the people already in the country to pursue microfabrication careers. A dozen schools within Auckland's low-income communities are already addressing this issue. The temporary solution is the Maniakalani ('hook from heaven') project: "It provides the predominantly Maori and Pasifika students with access to digital technology at school and at home via a subsidized rent-to-own scheme for netbooks, and supports more digital approaches to teaching and learning." (Futureintech, 2015)

The ideal situation for technology based companies in New Zealand would be a mutual agreement between Maori and the companies themselves that microfabrication is the most important field to pursue in the near future. This is because using resources, such as labor and manufacturing, from other countries may harm New Zealand's economy by taking jobs away from New Zealanders (Futureintech, 2015). The Maori economy could assist high tech industries in New Zealand's future, particularly because New Zealanders will be more able to keep companies in the country. Keeping the money and products in New Zealand is a better alternative to selling a potentially successful product to a large foreign company (Futureintech, 2015). The lack of skilled labor in this industry may prove to be such a significant problem that production moves overseas.

2.6.2 Maori Tapu

Tapu is a Maori cultural belief which is very similar to the “taboo” belief in other cultures. Tapu says that certain actions are prohibited in society due to the notion that these behaviors will offend the gods or violate something to be held sacred. It is vitally important to think about what this concept means to the people of New Zealand. Obviously, tapu is important to the Maori people because they strictly avoid anything that would violate the rules of tapu so that they can hopefully reach a state of noa, which is the complete absence of the restrictions of tapu.

The original belief systems of Maori ancestors has caused the Maori to adopt a cautious view of the world, much like many other cultures. An enormous aspect of tapu in the Maori culture revolves around the ideas of tribes or families sticking together and working toward the greater good of the group. Robert Joseph explains, “Given this ideal, there are obvious questions around the effects of a collectivist view in a seemingly individualistic world. The impact of the rise in urban Maori as well as many Maori overseas and (generally speaking) their seeming lack of affiliation with traditional tribal structures further complicates things but clearly needs to be taken into account" (Joseph, 2010). The Maori are familiar with a collectivist view of the world, so many of them may not consider an individualistic career. Most scientific careers are individualistic by nature because they are based on individual contributions. This is reflected in the microfabrication industry. It is extremely important to consider the views of the Maori, because it would be unwise to try and convince them to pursue a microfabrication career if it goes against their beliefs.

Urbanization and the creation of more factories and research facilities for microfabrication will generate more job positions for individuals in New Zealand. The more that Maori get involved in microfabrication careers, the more their peers may view them as violating the laws of tapu because they are migrating away from tribal and family life and striving toward individual success. This is why the expansion of the microfabrication industry might not be regarded by New Zealanders as a positive movement, especially in areas with high Maori influence.

2.6.3 Maori Tertiary Education

One of the largest institutions in New Zealand that deals with microfabrication is the University of Auckland shown in Figure 6. This university is home to 41,953 students (University of Auckland PDF, 2014). It is the largest and highest-ranked university in New Zealand, rated as high as 82nd in the world according to Quacquarelli Symonds (QS) World University Rankings. Proof of this university's importance also comes in the form of its research prowess. "The University of Auckland is New Zealand's largest research organisation with more than 13,000 staff and postgraduate students involved in fundamental and applied research. It generates around $230 million in annual research revenue" (University of Auckland, 2014). The University of Auckland has 31% of research funding as well as 35% of the top rated research professors in all of New Zealand (University of Auckland, 2014). Based on this information, it is clear that any research-based industry should consider stemming from this university and possibly involving it in a cluster.

Figure 6: University of Auckland (Grafton Campus, 2008)

The University of Auckland does not have many Maori involved in the technological programs that it offers such as microfabrication. According to the University of Auckland website,

there are less than 2000 Maori enrolled at the school right now (University of Auckland Maori, 2014). The University may try to incorporate more Maori into their Microfabrication Facility in the future because it is much more expensive to request skilled labor from overseas. If the Maori do become involved in the microfabrication industry, this could help solve the lack of skilled labor issue. However, there are other potential solutions to this problem, and the success of the microfabrication industry does not rely on the involvement of the Maori.

2.7 Environmental Concerns

The microfabrication industry involves many processes that result in hazardous chemical waste. Some people may not support the industry because of these harmful environmental effects. In New Zealand, a country with high environmental standards, people may be especially disapproving of these practices.

2.7.1 Environmental Hazards of Microfabrication Industry

One of the most harmful practices related to this industry is etching. During etching, a photoresist is developed and installed on a wafer. This wafer's silicon dioxide layer is then stripped using a chemical solution, but the photoresist remains on the wafer. Etching is important because it is the best way to secure a photoresist to a wafer to perform a desired function. There are two types of etching: wet etching and dry etching. Wet etching uses chemicals such as hydrofluoric acid, sulfuric acid, nitric acid, and hydrogen peroxide to strip the silicon dioxide layer off the wafer at room temperature or warmer environments. Researchers developed dry etching in order to strip certain layers that wet etching cannot. There are even more chemicals used in dry etching, such as chlorine, hydrogen bromide, fluorocarbons, and fluorine (Manufacture of Semiconductors, Pages 30-31).

All of these chemicals can harm the environment of New Zealand in one way or another. The Environmental Protection Agency drafted a report about the semiconductor industry which

explains, "[These] physical and chemical processing steps occur at four process operation areas … A variety of pollutants may be emitted at these stations. These include acid fumes and organic solvent emissions from cleaning, rinsing, resist drying, developing, and resist stripping; hydrogen chloride emissions from etching; and other various emissions from spent etching solutions … In addition to process related emissions, air emissions may also result from onsite treatment of industrial wastewater" (Manufacture of Semiconductors, Pages 35-36). Clearly, there are plenty of worries concerning the environmental impacts of the microfabrication industry. Specifically in the semiconductor portion of the industry, companies must consider the effects of the many different pollutants produced. New Zealand citizens are not likely to support an industry with harmful environmental practices, so companies must consider these opinions before developing a cluster with unfavorable practices.

2.7.2 Progress on Reducing Pollutants

Many people who are familiar with microfabrication recognize that it is harmful to the environment, so the United States put into place procedures in order to reduce hazardous air pollutants (HAP). Between 1987 and 1994, technological advances reduced HAP releases per area of silicon substrate from nearly 0.08 to 0.01 pounds per square inch. This is a significant improvement, which is exactly what the Semiconductor Industry Association (SIA) hoped to achieve for the industry. A study by the SIA found that "HAP usage in the semiconductor industry is declining due to regulatory, worker safety, and cost pressures, and the trend is likely to continue. Many HAP materials used in semiconductor manufacture have been replaced by HAP-free materials" (Manufacture of Semiconductors, Pages 37-38). If the microfabrication industry continues to grow in New Zealand and becomes as widespread as it is in the United States, organizations such as the New Zealand Environmental Protection Authority can put regulations in place to lower HAP levels. The people of New Zealand will more likely support the industry if

the government assures them that the environment will be protected even as the industry expands.

Chapter 3: Methods

This project will help Callaghan Innovation establish a microfabrication cluster in New Zealand by collecting and analyzing data from key stakeholders in the industry and creating recommendations to develop the cluster.

The first objective of the project is to evaluate the current state of the microfabrication industry and the needs of the companies. We will accomplish this through the use of expert interviews with company representatives. The second objective is to collect and evaluate the opinions and knowledge of New Zealand residents pertaining to the microfabrication industry. We will collect this data through the use of surveys that the team will administer in person in Wellington, Auckland, and Christchurch. This project investigates the general public's awareness and support for the growing microfabrication industry in New Zealand. We will survey a variety of people in order to gain full understanding about all of the different culture groups in New Zealand. The last objective of the project is to determine the environmental and cultural impacts the microfabrication industry might have. To accomplish this objective, we will conduct interviews with Maori, interviews with government and industry organizations, and surveys with the general public.

3.1 Objective 1: Evaluating the State of the Industry

Our first objective is to gain a deeper understanding of the current state of the microfabrication industry in New Zealand. This is important because it provides information about the aspects of the cluster that are already in place, the expectations of current and potential organizations involved, and what still needs to be done in order to further develop the cluster. To identify the key problems that we need to address, we will conduct interviews with a variety of industry stakeholders including company officials, researchers, and universities. The final recommendations will reference the data obtained from these interviews.

3.1.1 Interview Design

The basic design of the interviews will be semi-structured face-to-face interviews. The team will use these interviews to gather data on the current state of the industry and will focus on the views and opinions of representatives from the various companies and research institutions located in New Zealand. The first few questions will be about the individual's role in the company or institution and the industry. From there, the questions will get broader and focus on their views and opinions of the industry as a whole. Some of the later questions will inquire about the strengths and weaknesses of the microfabrication industry as well as the future of the industry. The interview questions are in Appendix A.

3.1.2 Interview Strategy

With the structured face-to-face interview design that our team chose, one interviewer will ask questions to the interviewee and another team member will take notes on a computer that the team will later use for analysis. If the interviewee allows it, we will also record each interview with the intentions of gathering quotes and having the ability to review past interviews. In conducting the interview, there will be a prepared set of questions to use as discussion points.

3.1.3 Stakeholders to be Interviewed

Currently, we have a list of companies and organizations that we intend to interview in New Zealand. Upon arrival, we will search for more organizations in the microfabrication field to interview through Callaghan Innovation. Some companies and organizations that have the potential to form a cluster that we plan to talk to include the ones shown below in Figure 7.

Name	Location	Role
Pure Depth	Auckland	Industry
Rakon	Auckland	Industry
Helix Industries	Christchurch	Industry
Triode	Auckland	Industry
Shamrock Industries	Christchurch	Industry
Adept Medical	Auckland	Industry
Perry Engineering	Wellington	Industry
Living Cell Technologies	Auckland	Industry
Mars Bioimaging	Christchurch	Industry
Victoria University of Wellington	Wellington	Education
University of Auckland	Auckland	Education
Nanomaterials Devices Group	Wellington	Research
Environmental Protection Authority	Wellington	Government
Worksafe NZ	Wellington	Government
FutureInTech	Wellington	Other

Figure 7: Stakeholders

3.1.4 Interview Data Analysis

In order to analyze the data that is gathered from the interviews, we will use coding. We will decide upon the various key topics and code the interview data with them. Each team member will code the data independently to reduce bias. Through coding, we will be able to analyze the qualitative data retrieved from the interviews. From the coding output data, the team will analyze the current state of the microfabrication industry.

3.2 Objective 2: Analyzing the Opinions of New Zealand Citizens

Our second objective is to gather information on the opinions and knowledge of the citizens of New Zealand about industry expansion, pollution, and cultural concerns. Through the use of short face-to-face surveys in Wellington, Auckland, and Christchurch, we will be able to understand the attitude that the public has towards technology and industry growth in New Zealand. This is important because without local support, sustaining the cluster will be difficult. These findings will impact our final recommendations.

3.2.1 Survey Design

The team will conduct surveys on the street and record responses on clipboards. The first few questions will be simple demographics about the participant. The next few questions will pertain to their views and opinions of the microfabrication industry, including whether or not they know what microfabrication is. The survey questions are in Appendix B.

3.2.2 Survey Strategy

A potential problem that we could encounter would be a lack of survey participants. In order to achieve a large sample size, we will situate ourselves in crowded places around Wellington, Auckland, and Christchurch where tourists are not likely to visit, such as grocery stores or banks. To ensure that we will gather information from all cultures across New Zealand, we will conduct surveys in Maori neighborhoods. Another potential problem is that some people we survey may have little knowledge of the microfabrication industry. To address this issue, we will include a short explanation before our survey questions describing common devices and applications. The surveys will be short, lasting three to five minutes, and will be aimed at passersby. We will record responses on clipboards, enter the data into a computer, and analyze it at a later point. This survey will be a convenience sample and therefore cannot be completely random.

3.3 Objective 3: Determine the Environmental and Cultural Impacts

It is important to ensure the success and growth of the microfabrication cluster in New Zealand, as it would offer much to its citizens. However, we cannot make industry recommendations without first determining its impact on the environment and the culture in New Zealand. Our team hopes to gather this information through the use of the same interviews and surveys aforementioned.

3.3.1 Exploring Potential Environmental Impacts

In addition to the current state of the microfabrication industry in New Zealand, our team will interview with the various stakeholders concerning the environment. These stakeholders include government organizations and local residents, specifically focusing on Maori as this group has a cultural significance in New Zealand. To explore the environmental impacts, we will include questions concerning possible pollution concerns and how the industry hopes to deal with them. Once we collect the data from the surveys and interviews, the team will individually code the gathered information in the same way as previously mentioned. Analysis from this coding will provide us with information that will influence the final recommendations.

3.3.2 Exploring Potential Cultural Impacts

The purpose of surveying the local population in New Zealand is not only to gain the views and opinions of the public on the microfabrication industry, but also to learn about the cultural concerns that many people may have. In addition to these surveys, the team will conduct semi-structured interviews with Maori in order to understand the cultural concerns corresponding to the microfabrication industry. These interview questions are in Appendix C. We will set up new interviews based off the contacts from previous interviewees. Callaghan Innovation has connections within the Maori community which we hope to use to schedule interviews. Once the team has collected the data, we will code it as previously mentioned. The team will identify

possible cultural conflicts with the microfabrication industry through the analysis of the data collected through these surveys and interviews. This information will ultimately influence the final recommendations.

3.4 Final Recommendations

Once the key issues with the cluster become apparent, the team will suggest recommendations regarding how to move forward with the formation and maintenance of the cluster. We will form these recommendations by taking into account perspectives from all of the major stakeholders. With these recommendations, we aim to help Callaghan Innovation establish a microfabrication cluster in New Zealand.

Bibliography

- Analog Devices. (2015). MEMS. Retrieved November 13, 2015, from http://www.analog.com/en/products/mems.html
- Bascand, G. (2012, November 15). Media release: Māori population grows and more live longer. Retrieved November 15, 2015, from http://www.stats.govt.nz/tools_and_services/media-centre/additional-releases/maori-population-estimates-15-nov-2012.aspx
- Bishop, Paul L. (Designer). (2007, October 7-11). Design of the disposable on-chip sensor [digital image]. Retrieved from https://www.researchgate.net/publication/266495697_ENVIRONMENTALLY-FRIENDLY_DISPOSABLE_HEAVY_METAL_ION_SENSORS_USING_PLANAR_BISMUTH_MICROELECTRODES_FOR_IN_SITU_ENVIRONMENTAL_MONITORING
- Bubendorfer, A., Liu, X., & Ellis, A. (2007). Microfabrication of PDMS microchannels using SU-8/PMMA moldings and their sealing to polystyrene substrates. Smart Mater. Struct. Smart Materials and Structures, 16(2), 367-371. Retrieved November 1, 2015, from http://iopscience.iop.org/article/10.1088/0964-1726/16/2/015/pdf
- Callaghan, P., & Blaikie, R. (2009). The MacDiarmid Institute for Advanced Materials and Nanotechnology: A New Zealand Centre of Research Excellence. IJNT International Journal of Nanotechnology, 6(3-4), 298-311.
- The CardioMEMS HF System [digital image]. (2015). Retrieved from http://www.sjm.com/cardiomems
- Castalia. New Zealand Manufacturing Sector: Its Dynamics and Competitiveness. (2014, February 1). Retrieved November 8, 2015, from

https://www.businessnz.org.nz/__data/assets/pdf_file/0005/76550/NZ-Manufacturing-Report-2014.pdf

- Draper (n.d.). Welcome to Draper. Retrieved November 13, 2015, from http://www.draper.com/
- Feeney, R., & Kounaves, S. P. (2000). Microfabricated ultramicroelectrode arrays: Developments, advances, and applications in environmental analysis. *Electroanalysis*, *12*(9), 677-684.
- FutureInTech. "Creative, smart, hardworking and brown": The future of the IT industry in New Zealand. (2015, August 1). Retrieved November 15, 2015, from http://www.futureintech.org.nz/enews/schools/story.cfm?ID=71
- Griffiths, D. (Creator). (2013, May 2). Proportion of employed by ethnic group and skill level [Graph]. Retrieved from http://www.stats.govt.nz/browse_for_stats/income-and-work/employment_and_unemployment/skills-employed-people.aspx
- Henderson, J. (2015, March 2). NZ leading the charge as region shifts towards Internet of Things solutions. Retrieved December 5, 2015, from http://www.reseller.co.nz/article/569262/nz-leading-charge-region-shifts-towards-internet-things-solutions/
- Huang X, "A differential dielectric affinity glucose sensor. - PubMed - NCBI", *Ncbi.nlm.nih.gov*, 2015. [Online]. Available: http://www.ncbi.nlm.nih.gov/pubmed/24220675. [Accessed: 13- Dec- 2015].
- Joseph, R. (2010). Legal Challenges at the Interface of Maori Custom and State Regulatory Systems: Wahi Tapu. Retrieved November 15, 2015, from file:///C:/Users/Tyler/Downloads/Legal_challenges_at_the_interf.PDF
- Key Statistics 2010-2014. (2014). Retrieved November 15, 2015, from https://cdn.auckland.ac.nz/assets/central/about/the-university/documents/Website Key stats Pdf- EFTS & FTE -2010-2014.pdf

- Key statistics. (2014). Retrieved November 15, 2015, from https://www.auckland.ac.nz/en/about/the-university/new-zealands-leading-university/key-statistics.html
- Manufacture of Semiconductors -- Background Information for Proposed Standards. (2001, February 1). Retrieved December 6, 2015, from http://www3.epa.gov/airtoxics/semicon/smatr_bid.pdf
- Māori students. (2014). Retrieved November 15, 2015, from https://www.auckland.ac.nz/en/about/eo-equity-office/eo-information-for-students/eo-maori-students.html
- Massachusetts Technology Transfer Center. (2015). About MATTCenter - The Massachusetts Technology Transfer Center. Retrieved November 22, 2015, from http://www.mttc.org/about-mattcenter/overview/
- MassTech. (2015). Cluster Development in the Innovation Economy. Retrieved November 22, 2015, from http://masstech.org/innovation-institute/cluster-development
- McSeveney, E. (2014, October 14). The 2011 Christchurch earthquake and other recent earthquakes. Retrieved November 22, 2015, from http://www.teara.govt.nz/en/historic-earthquakes/page-13
- MEMS & Nanotechnology Exchange. (unknown) What is MEMS Technology. Retrieved from https://www.mems-exchange.org/MEMS/what-is.html
- MicroChem: Innovative Chemical Solutions for MEMS and Microelectronics. (n.d.). Retrieved October 29, 2015, from http://www.microchem.com/index.htm
- Ministry of Health NZ,. (2015). *Diabetes*. Retrieved 15 November 2015, from http://www.health.govt.nz/your-health/conditions-and-treatments/diseases-and-illnesses/diabetes

- MIT/NTU Center for Polymer Microfabrication (CPM). (n.d.). Retrieved November 3, 2015, from http://web.mit.edu/cpmweb/index.html
- Nanoscience Nanotechnologies. (2006, December 1). Retrieved November 22, 2015, from file:///C:/Users/Tyler/Downloads/main_9ba0c67536b23a9592a1040bbd573688.pdf
- Part of the Medical School buildings at Grafton [Photograph]. (2008) Retrieved from: https://en.wikipedia.org/wiki/University_of_Auckland#/media/File:Faculty_of_Medical_and_Health_Sciences,_University_of_Auckland.jpg
- Productsfromnz.com,. (2015). *Economy of New Zealand - About New Zealand - Products from New Zealand*. Retrieved 15 November 2015, from https://productsfromnz.com//browse_1821
- Productsfromnz.com,. (2015). *Economy of New Zealand - About New Zealand - Products from New Zealand*. Retrieved 15 November 2015, from https://productsfromnz.com//browse_1821
- Sjm.com,. (2015). *CardioMEMS™ HF System | St. Jude Medical*. Retrieved 15 November 2015, from http://www.sjm.com/cardiomems
- Smith, D. R. (Designer). (2012, January 13). A sensor set with functionalized and reference probes is inserted into a milk conduit [digital image]. Retrieved from http://www.photonics.com/Article.aspx?AID=32591
- Smith, D., & Gottfried, D. (2015). MEMS Technology Tackles Food and Agricultural Challenges. Retrieved November 8, 2015.
- Suzuki, H. (2000). Microfabrication of chemical sensors and biosensors for environmental monitoring. *Materials Science And Engineering: C*, *12*(1-2), 55-61. http://dx.doi.org/10.1016/s0928-4931(00)00158-2
- Tapu - sacred MÄ ori code - Tourism New Zealand Media. (n.d.). Retrieved November 15, 2015, from http://media.newzealand.com/en/story-ideas/tapu-sacred-maori-code/
- The Treasury. (2012). Industrial Sector. Retrieved November 8, 2015.

- The Treasury. (2015, April 15). New Zealand Economic and Financial Overview 2015. Retrieved October 31, 2015, from http://www.treasury.govt.nz/economy/overview/2015
- University of Auckland (n.d.). *Auckland Microfab Research*. Retrieved from http://microfab.auckland.ac.nz/research/
- Valerie, L. (2005). The Development of International Industry Clusters: A Complexity Theory Approach. *Journal of International Entrepreneurship, 3*(1), 71-97. doi:10.1007/s10843-005-0307-2
- Wheeler, G. (2013, February 20). Manufacturing decline not just a dollar story. Retrieved November 8, 2015, from http://www.rbnz.govt.nz/research_and_publications/speeches/2013/5150125.html
- Yang, W., Yu, H., Wei, F., Li, G., Wang, Y., & Liu, L. (2015). Selective pattern of cancer cell accumulation and growth using UV modulating printing of hydrogels. *Biomedical Microdevices*, *17*(6). http://dx.doi.org/10.1007/s10544-015-0013-3
- Yewdall, A. (2015, April 30). INSPIRATION: Engendering passion for science and innovation across society - MacDiarmid Institute. Retrieved November 22, 2015, from http://www.macdiarmid.ac.nz/about-us/strategic-plan/inspiration-engendering-passion-science-innovation-across-society/
- Zou, Z., Jang, A., Wu, P. M., Do, J., Han, J., Bishop, P. L., & Ahn, C. H. (2007). Environmentally-friendly disposable heavy metal ion sensors using planar bismuth microelectrodes for in situ environmental monitoring. In *Eleventh International Conference on Miniaturized Systems for Chemistry and Life Sciences Paris France*.

Appendix A: Interview Questions for Company Representatives

We will be using some of these interview responses in our final report, so if there is any sensitive or confidential information that we should not publish, let us know.

1. Can we record this interview?
2. Which part of the microfabrication industry are you involved in?
3. What is your job title?
4. What is your job description?
5. What do you imagine the future of microfabrication to be in New Zealand?
6. What are, in your opinion, the key factors driving the microfabrication industry?
7. What is, in your opinion, holding the microfabrication industry back?
8. What is your experience with the Internet of Things (IoT) and how important do you think it is for microfabrication to focus on this?
9. What are the strengths of the microfabrication industry?
10. What are the weaknesses of the microfabrication industry?
11. What do you know about industry clusters?
12. How do you think your organization would benefit from joining a cluster?
13. What types of government regulations affect your position?
14. How do you think the microfabrication industry impacts the New Zealand culture?

Appendix B: Survey Questions

1. Age (in ranges)
    - Under 18
    - 18-24
    - 25-34
    - 35-44
    - 45-54
    - 55-64
    - 65+
2. Ethnicity: Pakeha/Maori/Pasifika/Non-New Zealander (multiple choice question)
3. Highest completed level of education: none/secondary school/associates/bachelors/masters/professional/doctorate
4. Are you currently employed in a technological field? If so, what field?
5. How familiar are you with the microfabrication industry in New Zealand?
    - Never heard of it – 1
    - Heard of it, but not familiar – 2
    - Quite familiar - 3
    - Very familiar and work in the field - 4
6. How concerned are you about pollution from factories?
    - Not concerned at all – 1
    - Extremely concerned - 5
7. Do you have any cultural concerns about industry expansion in New Zealand?

Appendix C: Interview Questions for Maori

1. Can we record this interview?
2. Age (in ranges)
    - Under 18
    - 18-24
    - 25-34
    - 35-44
    - 45-54
    - 55-64
    - 65+
3. Highest completed level of education: none/secondary school/associates/bachelors/masters/professional/doctorate
4. Are there any cultural issues with the manufacturing industry that affect you?
5. What level of involvement do you think the Maori want to have in the microfabrication industry?
6. How concerned are you about pollution in the manufacturing industry?