FROM SEED TO SAIL:

THE SUSTAINABLE AND COMMERCIAL VIABILITY OF BOAT BUILDING WITH HEMP BIO-COMPOSITES IN AOTEAROA NEW ZEALAND

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Abstract

This thesis investigates the commercial viability and sustainability of hemp bio-composites for Aotearoa New Zealand's boat-building industry. The research employs a qualitative approach, primarily through 20 interviews with boat manufacturers and hemp industry experts, to gather insights on perceptions, challenges, and opportunities associated with hemp bio-composites and its ability to replace fibreglass. It explores the benefits and challenges of using hemp bio-composites in boat building as well as industry professionals' attitudes and perceptions of the material.

The study uncovers that industry insiders have noted a rising interest in environmentally friendly materials, with hemp bio-composites emerging as a promising contender due to its ecological benefits and technical properties. The findings suggest that, for hemp bio-composites to become a viable substitute, boat builders need to be presented with evidence that the material would deliver equal performance at comparable costs to established materials. Key challenges identified by the interviewees include the high cost of bio-resin epoxies (matrix mediums) needed to reinforce hemp fibres in composite manufacturing and the absence of a robust local hemp fibre supply chain. Samples of hemp fibre-reinforced composites were created for demonstration purposes during interviews with industry experts, aiding the interviewees in the practical understanding of the material's potential and building a sense of familiarity with the new material.

While hemp bio-composites are recognised as a sustainable and potentially marketable alternative, their widespread use in the boat building sector is contingent upon overcoming existing barriers. The thesis concludes with a call for further research and development, focusing on performance testing, supply chain improvements, and educational efforts to promote hemp bio-composites in Aotearoa New Zealand and beyond.

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Attestation of Authorship

“I confirm that this submission is my original work and, to my best understanding, does not include any prior publication or written material by another individual or organisation. Furthermore, it does not contain portions submitted to obtain any other academic degree from a university or any other institution of higher learning.”

Yours sincerely,



Gautam Madhavan Nair

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CHAPTER 1 – INTRODUCTION

1.1. BACKGROUND

The exploration of sustainable materials for industrial applications has become increasingly crucial, specifically with respect to environmental concerns and resource sustainability. Among these, bio-composites, particularly those reinforced with natural fibres, have achieved international attention because of their potential to replace traditional materials which are often environmentally damaging. This thesis examines expert's perceptions of/ assessment of the commercial viability of hemp bio-composites in Aotearoa New Zealand, specifically within the boat building industry.

Hemp, a historically versatile and sustainable crop, has seen a resurgence in interest due to its environmental and mechanical advantages. Globally, the bio-composite industry has been evolving, with natural fibres like hemp making competitive entry due to their lower environmental footprint and comparable performance metrics to traditional materials like fibreglass.

Aotearoa New Zealand's relationship with boat building is deeply ingrained in its culture and history, dating back to the Polynesian ancestors and their oceanic voyages. The modern Aotearoa New Zealand's boat building industry is recognised for its high standards and innovative approaches, making it an ideal candidate for integrating new, sustainable materials like hemp-based bio-composites. Additionally, Aotearoa New Zealand's stance on environmental conservation and sustainable practices further accentuates the relevance of this research.

Despite hemp's promising attributes, its adoption in industrial applications like boat building faces challenges. These include technological hurdles, market perception, cost implications, and regulatory environments. This thesis seeks to investigate these challenges and assess the potential of using hemp bio-composites for boat building in Aotearoa New Zealand in light of the nation's industrial landscape environmental policies, and market dynamics.

The significance of this research lies not only in its potential contribution to the boat building industry but also in its broader implications for sustainable industrial practices. By examining the commercial viability of hemp bio-composites, this study aims to provide insights that could influence future material choices, not just in Aotearoa New Zealand but also globally, steering industries towards more environmentally responsible and sustainable practices.

In conclusion, this thesis will explore the complex interplay of technical, economic, and environmental factors that influence the adoption of hemp bio-composites in Aotearoa New Zealand, offering a comprehensive analysis that could pave the way for a more sustainable future in industrial material usage.

1.2. RESEARCH AIMS AND OBJECTIVES

This research aims at investigating the commercial viability and sustainability of adopting hemp bio-composites within Aotearoa New Zealand's boat building sector. In the current market, most industry sectors have an increasing demand for environmentally friendly, sustainable materials and products. This study analyses the potential of hemp bio-composites as an alternative to traditional materials such as fibre glass used in composite boat manufacturing. The research explores the perceptions of relevant stakeholders such as boat builders and hemp experts with regards to the potential performance, economic viability, climatic benefits, regulatory barriers, potential markets, and opportunities for adoption by the Aotearoa New Zealand Marine industry.

This research aims to contribute to developing and implementing sustainable practices in the boat building sector and promote the usage of natural fibres and their renewable qualities. The research study seeks to address the challenges of climate change, pollution, and dependency on fossil fuel-based resources within the marine sector. It further aims to promote innovation and encourage the growth of the local hemp industry in Aotearoa New Zealand, thereby contributing to the country's green economy and job creation.

A qualitative methodology was employed in this research. Data collection involved interviews with potential stakeholders from the boating industry, such as composite manufacturers, experts in boating and manufacturing, retail businesses and experts engaged in industrial hemp growth, processing and product sales. These interviews helped generate potential insights into the practical implications of adopting hemp bio-composites as a fibreglass composite alternative and the concerns and expectations that the industry stakeholders have. In addition, samples of hemp bio-composite materials were developed and presented to the interviewees to gather direct feedback on their performance and potential applications in boat building. The findings from this study are expected to identify the key factors influencing the adoption of hemp bio-composites in the Aotearoa New Zealand boat building sector along with suggestions for how to overcome the identified barriers.

The research also outlines future research and development opportunities, paving the way for more exploration and innovation in the science of sustainable boat building materials.

1.3. RESEARCH QUESTIONS

The study seeks to address the following research questions.

a) Do hemp bio-composites have a commercialisation potential in the boat building sector and could they replace fibreglass composites?
b) What are the regulatory barriers and production constraints for using hemp bio-composites in boat building, and how can they be addressed?
c) What opinions and reservations do the stakeholders, such as boat builders and composite product manufacturers, have about adopting it?

1.4. SCOPE AND LIMITATIONS

The entire scope of this research is limited to the boating industry alone and the potential of replacing fibreglass composites. Boats are built using various materials; however, this research focuses only on the most pollutive and resource-intensive manufactured

component, the fibreglass composite. While boat building involves a variety of materials, this research only considers the suitability of natural fibre composites as a viable substitute for fibreglass composites. Samples of the bio-composites were developed as part of the research. They are concept-based and will not be tested for their mechanical and chemical properties. Instead, the samples developed were used as a talking point or a conversation starter within the Aotearoa New Zealand boat building community during the interview and discussion sessions.

CHAPTER 2: LITERATURE REVIEW

This chapter offers a detailed analysis of advantages and disadvantages of using industrial hemp in the boat building sector. By exploring its potential as an environmentally friendly alternative and considering its economic implications, this chapter aims at understanding the issues and benefits of using industrial hemp in order to assess its potential for the boat building industry?

The review provides a general overview of the boat building sector and its reliance on fibreglass reinforced composites for manufacturing purposes. Specifically, the focus is on the boat building industry within Aotearoa New Zealand in order to explore the feasibility of adopting hemp fibre reinforced composites as a substitute for fibreglass. Furthermore, the chapter also dives deeper into how industrial hemp, as a versatile crop, has the potential to emerge as the leading contender among other natural fibres in replacing fibreglass. The gradual global recognition and adoption of industrial hemp due to its diverse range of end products are examined. Additionally, the chapter delves into the regulatory constraints surrounding industrial hemp and investigates its potential future influence on Aotearoa New Zealand's economy.

2.1. BOAT BUILDING IN AOTEAROA NEW ZEALAND

2.1.1. History

Aotearoa New Zealand has a rich and robust boat building history, with settlers building sailboats and ships since the 1820s (Glass & Hayward, 2001). By the 1870s, most sailing ships were replaced with steam engine ships. The primary material used for boat building was timber from Auckland and Northland. Before the 1900s, boat builders used native Kauri timber as it offered excellent resistance to seawater Some of the boats built during this period have lasted for over a century and are still in use (Kidd, 2006). One of the most popular boats, reminiscent of the past, is an old steamer named the Earnslaw, used as a cruise in Lake Wakatipu, Queenstown (McLean, 2006; Nathan, 2007). During this period, well-organised racing regattas were popularised with different classes of boats competing,

and recreational cruising became popular around the islands of the Hauraki Gulf (Kidd, 2006). Since the 1920s, at the Bay of Islands, there have been “cream trip” boat tours (a route used by ships to transport goods to and fro from Bay of islands) for tourist sightseeing (Orange, 2015).

The growth of the Aotearoa New Zealand boat building industry was primarily due to the geographical conditions. The geographical conditions in Aotearoa New Zealand both promoted the growth of a boat building industry in general and provided an ideal setting for developing innovative designs. Thus, the fact that Aotearoa New Zealand is an island, meant that boat builders could try out their designs in a large variety of settings, including calm lakes, sheltered bays, and in rough weather out at sea. As a result, NZ boat builders soon gained an international reputation for building better quality boats (Chetty, 2004). Auckland became a hot spot for yacht builders due to its favourable weather conditions for sporting events and expansive cruising offerings to popular destinations in locations such as the Hauraki Gulf, Northland coast and the Coromandel Coast that cater to bigger yachts (Kidd, 2006; McLean, 2006). The super yacht segment grew fastest during this period, leading to Aotearoa New Zealand building an international brand name, with its boat builders and designers winning several world-class awards (Chetty, 2004; Glass & Hayward, 2001). Aotearoa New Zealand boat builders have managed to maintain this high standard of work; as recently as in 2021, Stabicraft's 2250 Ultracab WT won the prestigious ‘Best of the Best’ Red Dot Award for global product design in 2021 ("Kiwi Boating Boom," 2021). Their boats are made of glass fibre reinforced composites, a popular choice of material among most boat builders in Aotearoa New Zealand, so the research will focus on fibre reinforced composites.

2.1.2. Current State of the Industry and Use of Fibre Reinforced Composites

By the 1970s, fibreglass boat building was introduced to build faster boats and catamarans (Kidd, 2006). New Zealand boat building is renowned for its innovative “Kiwi-designed” ingenuity that led them to win the America’s Cup twice. The use of fibreglass in their racing yachts propelled their brand image. One of the most famous examples of a Kiwi-designed product is the ingenious jet boat designed by Bill Hamilton in the 1950s. It is a small craft used for shallow waters. The company still builds them in Christchurch. Another example of

innovative New Zealand designs include bigger sail yachts, like the Tiara, which feature helipads, built completely in Auckland. (McLean, 2006).

In the 1980s, the traditional waka ama (canoe with outrigger) gained popularity in Aotearoa New Zealand. Most traditional Māori waka (boats /canoes) were made by skilled craftsmen carving a tree trunk to form the hull. With advancements in boat building, designers started building the waka ama in fibreglass, making them light and easily manoeuvrable. Though the waka ama (Figure 2) has been modernised both in terms of design and manufacturing processes, the boats and paddles are still inscribed and fashioned with Māori art, celebrating the tradition of fishing and racing (Barclay-Kerr, 2013).

Another example of modernisation of the waka is the Tairāwhiti waka hourua (Figure 1), built in 2017. The waka hourua was traditionally made out of tree trunks and was used in voyaging expeditions by the Māori. The Tairāwhiti Waka Hourua was constructed in fibreglass by Salthouse Boat builders Ltd and was the first contemporary Māori Voyaging catamaran built in Aotearoa New Zealand. The boat's design has a very traditional outlook and was made with modern materials like fibreglass composites and housed today's cutting-edge marine transportation technologies. (Heke, 2021).



Figure 1: Waka hurua (Waikato, 2021)



Figure 2: Fibreglass waka ama OC1 (Blythe, 2017)

Aotearoa New Zealand's boat building industry is primarily run by small businesses that do not focus in repetitive or mass production, but in custom building. As a cluster, the industry focuses on exports and comprises specialist firms that build boats for sports, leisure, sailing and power boats. Smaller ferries for transportation are also built by these firms. In the 1980s, an introduction of a 20% sales tax on commercial crafts led to the departure of several quality boat builders and designers to set up shops in other countries, and the

impact of that move can still be felt to date. However, this led businesses to pivot to more niche segments like custom boat building for racing and luxury yachts, which has led to international success (Chetty, 2004; Glass & Hayward, 2001). A contributing factor to the growth of the boat building industry and its contribution to innovation is Aotearoa New Zealanders' aspiration to be "boaties" (Figure 3), and their interest in international racing competitions (Glass & Hayward, 2001).

According to the NZ Marine Industry Association, there are 1.5 million boats in Aotearoa New Zealand, and its marine industry has a turnover of 2.9 bn NZD (2020), making it the largest manufacturing industry in the non-agricultural sector (*Annual Report Pūrongo ā-Tau 2021/22*, 2022). The market is performing well, with 28% domestic sales and 26% exports. 40% of the population participates in recreational boating in Aotearoa New Zealand. Since 2019, trailer boat sales have grown by 51% (see figure 4 and 5), with overall vessel purchases at 44,810 per year (*New survey reveals substantial growth in Aotearoa New Zealand boating market*, 2022). The influence of winning the America's Cup has been crucial in uniting and promoting the expansion of the boat building cluster in Aotearoa New Zealand. The small boat building businesses manufacture innovative products that seldom compete with each other but are differentiated in their product offerings. This cluster model strengthens the drive for innovation (Chetty, 2004; Glass & Hayward, 2001).

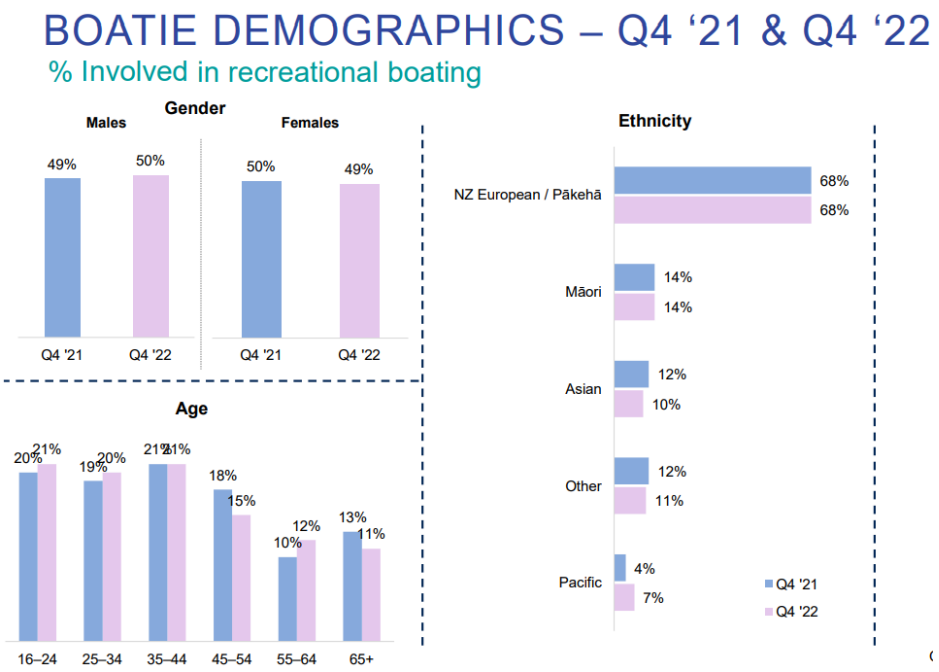


Figure 3: Boatie Demographics ("Top of the charts: Boating now Aotearoa New Zealand's top leisure activity," 2023)

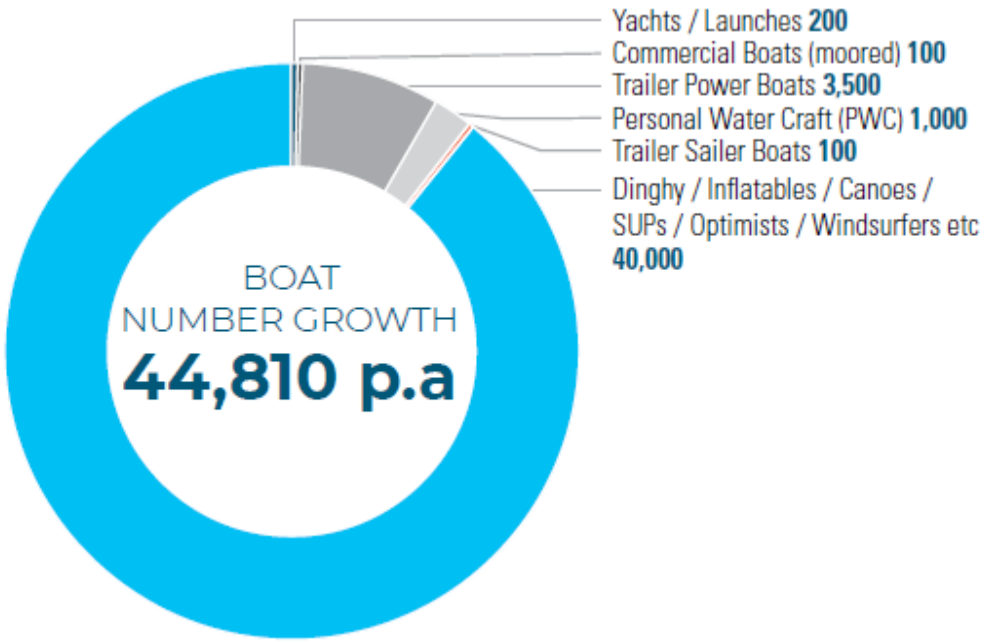


Figure 4: Estimated growth of boat numbers in Aotearoa New Zealand per annum ("The Electric Boat Revolution," 2022)

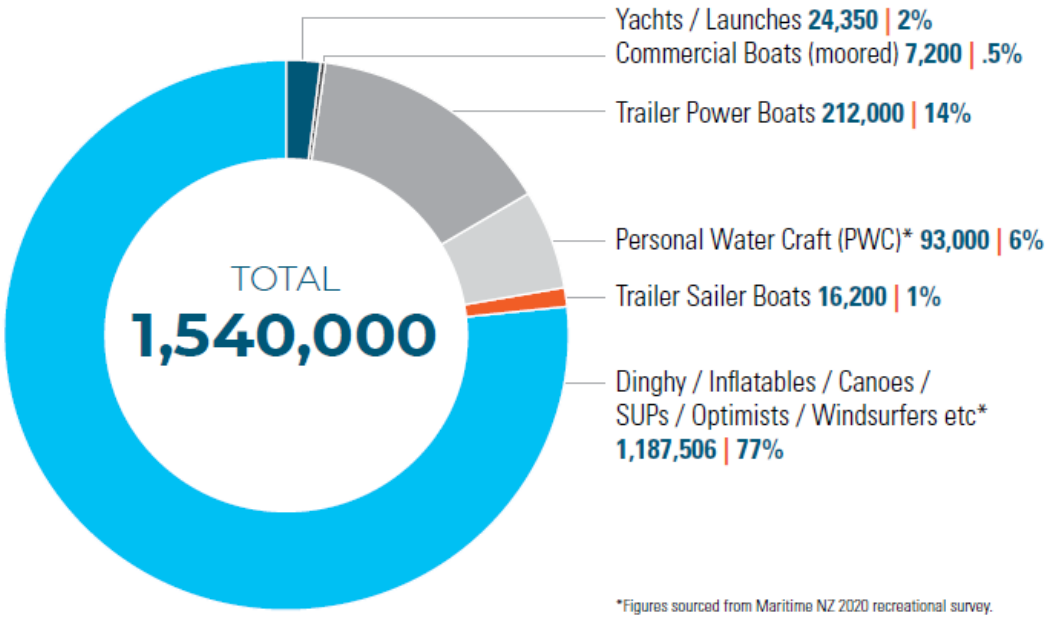


Figure 5: Estimated stock of boats in Aotearoa New Zealand ("The Electric Boat Revolution," 2022)

More than 500 companies (Figure 6) are registered with the Aotearoa New Zealand Marine Industry (NZmarine, 2023). About USD 122.71m worth of floating structures, ships, and boats were exported in 2022 (*Aotearoa New Zealand Exports of ships, boats, and other floating structures*, 2023).

NZmarine Statistics on the New Zealand Marine Industry

Comparison of the financial year ending March 2022 with calendar year 2019

Sources: PowerStats Ltd surveys 2022 and 2019
2022 results, version date: 6 September 2022
2019 results, version date: 24 November 2020

Comparison of the financial year ending March 2022 with calendar year 2019

Sources: PowerStats Ltd surveys 2022 and 2019
2022 results, version date: 6 September 2022
2019 results, version date: 24 November 2020

	Total revenue ($NZD million)			Domestic revenue ($NZD million)		
Business categories	2022	2019	% change	2022	2019	% change
Build - Boat builders (incl refit)	$796.7	$597.3	33%	$612.5	$432.1	42%
Build - Trailer manufacturers	$25.6	$16.3	57%	$24.9	$16.3	53%
Build - Naval architects and designers	$18.8	$16.5	14%	$12.7	$12.1	5%
Build - Engine distribution, repair and installation	$293.4	$258.8	13%	$284.7	$238.0	20%
Build - Imported material suppliers	$31.3	$20.4	53%	$30.7	$18.4	67%
Build - Imported equipment and chandlery	$253.8	$354.6	-28%	$231.6	$336.9	-31%
Build - Engineering and maintenance services	$30.5	$31.0	-2%	$25.7	$21.8	18%
Build - Electrical services	$36.7	$44.4	-17%	$28.0	$34.1	-18%
Build - Other services (incl haulage, cleaning etc)	$35.7	$13.8	159%	$29.0	$11.9	143%
Boat builders - subtotal	***$1,522.4***	***$1,353.0***	***13%***	***$1,279.6***	***$1,121.5***	***14%***
Deal - Importers and brokers	$207.0	$84.6	145%	$195.0	$77.3	152%
Deal - Trailer power boat dealers	$259.2	$171.6	51%	$254.4	$167.0	52%
Boat dealers - subtotal	***$466.2***	***$256.2***	***82%***	***$449.4***	***$244.3***	***84%***
NZ Manuf - Spar makers	$65.7	$61.5	7%	$13.1	$5.5	139%
NZ Manuf - Sail makers	$41.3	$45.6	-9%	$7.4	$4.8	54%
NZ Manuf - Electronic equipment	$213.7	$148.9	43%	$93.4	$21.7	330%
NZ Manuf - Major components	$152.5	$97.1	57%	$47.7	$16.7	186%
NZ Manuf - Boat fittings	$127.2	$55.3	130%	$41.6	$32.0	30%
NZ Manuf - Safety gear (incl. clothing)	$16.4	$8.6	90%	$9.1	$3.9	133%
NZ Manuf - Materials	$73.4	$49.7	48%	$30.3	$38.9	-22%
NZ Manufactured equipment - subtotal	***$690.1***	***$466.7***	***48%***	***$242.7***	***$123.6***	***96%***
Other - Brokers	$8.0			$7.6		
Other - Insurance	$30.9	$60.6	-49%	$26.0	$60.6	-57%
Other - Marketing and media	$13.1	$13.7	-4%	$8.8	$7.0	26%
Other - Yacht agent	$19.2			$8.0		
Other - All other	$63.3	$33.6	88%	$40.9	$32.5	26%
Supporting services - subtotal	***$134.5***	***$107.9***	***25%***	***$91.4***	***$100.1***	***-9%***
Marinas and drystacks	$84.1	$86.4	-3%	$76.3	$81.2	-6%
Supporting services - subtotal	***$84.1***	***$86.4***	***-3%***	***$76.3***	***$81.2***	***-6%***
Total	$2,897.3	$2,270.2	28%	$2,139.4	$1,670.7	28%

NB1: the 2022 boat builders value includes $315M of trailer powerboat manufacturing revenue
NB2: the 2019 boat builders value includes $213M of trailer powerboat manufacturing revenue
NB3: the 2019 "Engine distribution, repair and installation" data have been adjusted

Business categories	Export revenue ($NZD million)			Export revenue as % of total	
	2022	2019	% change	2022	2019
Build - Boat builders (incl refit)	$184.2	$165.2	12%	23%	28%
Build - Trailer manufacturers	$0.7			3%	
Build - Naval architects and designers	$6.2	$4.4	40%	33%	27%
Build - Engine distribution, repair and installation	$8.7	$20.8	-58%	3%	8%
Build - Imported material suppliers	$0.6	$2.0	-69%	2%	10%
Build - Imported equipment and chandlery	$22.2	$17.7	25%	9%	5%
Build - Engineering and maintenance services	$4.8	$9.2	-48%	16%	30%
Build - Electrical services	$8.7	$10.3	-15%	24%	23%
Build - Other services (incl haulage, cleaning etc)	$6.8	$1.9	259%	19%	14%
Boat builders - subtotal	***$242.8***	***$231.5***	***5%***	***16%***	***17%***
Deal - Importers and brokers	$12.0	$7.3	65%	6%	9%
Deal - Trailer power boat dealers	$4.8	$4.6	5%	2%	3%
Boat dealers - subtotal	***$16.8***	***$11.9***	***42%***	***4%***	***5%***
NZ Manuf - Spar makers	$52.6	$56.0	-6%	80%	91%
NZ Manuf - Sail makers	$33.9	$40.8	-17%	82%	89%
NZ Manuf - Electronic equipment	$120.2	$127.2	-5%	56%	85%
NZ Manuf - Major components	$104.8	$80.4	30%	69%	83%
NZ Manuf - Boat fittings	$85.6	$23.3	267%	67%	42%
NZ Manuf - Safety gear (incl. clothing)	$7.3	$4.7	55%	44%	55%
NZ Manuf - Materials	$43.0	$10.8	299%	59%	22%
NZ Manufactured equipment - subtotal	***$447.4***	***$343.1***	***30%***	***65%***	***74%***
Other - Brokers	$0.4			5%	
Other - Insurance	$4.9			16%	
Other - Marketing and media	$4.3	$6.7	-36%	33%	49%
Other - Yacht agent	$11.2			58%	
Other - All other	$22.4	$1.1	1974%	35%	3%
Supporting services - subtotal	***$43.1***	***$7.7***	***456%***	***32%***	***7%***
Marinas and drystacks	$7.8	$5.3	49%	9%	6%
Supporting services - subtotal	***$7.8***	***$5.3***	***49%***	***9%***	***6%***
Total	$757.9	$599.5	26%	26%	26%

Table 1: Comparison of the financial year ending March 2022 with the calendar year 2019, Pg 23 and 24 ("Top of the charts: Boating now Aotearoa New Zealand's top leisure activity," 2023)

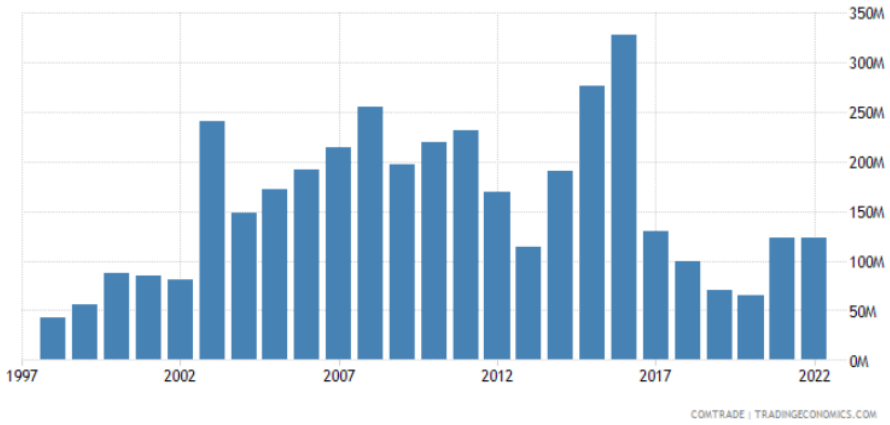


Figure 6: Revenue from export of boats, ships and floating structures by 500 companies in NZD Million within Aotearoa New Zealand (*New Zealand Exports of ships, boats, and other floating structures*, 2023)

Overall, the NZ boat building industry has an excellent future, as indicated in Table 1. With current employment of more than 10,000 people, the NZ boat building industry is bound to double in the next 10 – 15 years (NZTE, 2021). Aotearoa New Zealand's famous "kiwi innovation" attitude will be a game changer within the custom boat building sector that will surely benefit from micro production units owing to the fact that 3D printing is becoming progressively more accessible to a large variety of industries.

2.2. UNDERSTANDING FIBRE REINFORCED COMPOSITES

2.2.1. Introduction

Composites generally comprise two or more materials. They consist of one or more fibres or particulates in a continuous medium (known as matrix medium). Regardless of whether fibres are used in the composites, they can be either natural or synthetic, and the end product is referred to a fibre reinforced composite. The matrix medium is usually a thermoplastic or thermoset polymer used in order to ensure the fibres stay in the location they are aligned in. When more than one fibre is used, be it natural or synthetic, the composites become hybrid in nature. The fibre within the composite helps distribute any forces acting on it (Satheeshkumar & Jesuarockiam, 2014). This research focuses primarily on fibre reinforced composites since they are the most popular material used in the boat building industry.

Fibre reinforced composites are formed when specific amounts of resins and fibres are combined. This combination gives the structural and strength characteristics required for a composite component. Variation in the ratio of the resin to fibre determines the mechanical properties and functional requirements of the component developed (Dokos, 2013). Epoxy resins are commonly used in fibre reinforced composites as thermoset matrices. However, bio-epoxy resins are advocated due to the known endocrine-disrupting properties of widely used petroleum-based epoxy resins (SSUCHY, 2020). The best way to create eco-friendly fibre reinforced bio-composites would be to use natural fibres combined with a bio resin (soy, linseed, or sunflower-based), making the composite fully sustainable. Natural particulates can be combined with thermoplastics to create plastic injection moulded

components. PLA and PHA are two popular bio-based thermoplastics now commonly used to make natural bioplastics (Elseify et al., 2021).

2.2.2. Types of Fibres (Natural and Synthetic Fibres)

Fibre reinforced composites are made from reinforcing materials that can be either fibrous or particulate based. These composites can be made from fibres that are either natural or synthetic or a combination of both (see Figure 7). When derived from plants, animals, or minerals, these fibres are labelled natural fibres. The most commonly used natural fibres are wool, silk, flax, hemp, and jute. Fibres extracted from chemical processes are called synthetic fibres; most are petrochemical based. Synthetic fibre examples include glass, carbon fibre, or ceramic. Natural fibres also provide better strength and structural properties when combined with synthetic fibres. In combination, they are called hybrid fibres (Satheeshkumar & Jesuarockiam, 2014).

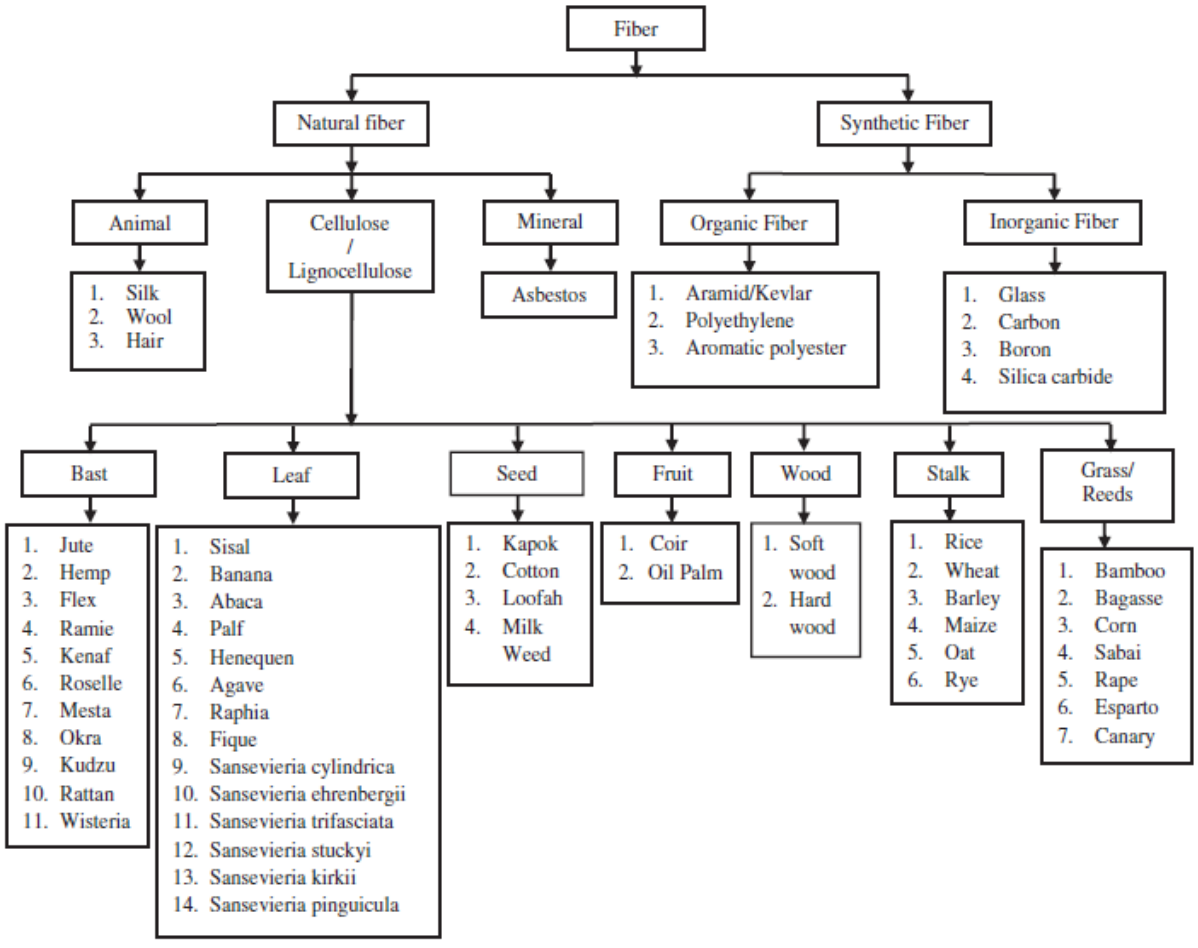


Figure 7: Natural and synthetic fibre classifications (Satheeshkumar & Jesuarockiam, 2014)

2.3. UNDERSTANDING SYNTHETIC FIBRE COMPOSITES

Synthetic fibre composites use various fibres like glass, carbon, and boron. For this research, our focus will be primarily on reinforced glass fibre composites (commonly known as fibreglass composite or GRP) since they are used worldwide in composite boat building.

2.3.1. Glass Fibre

Glass fibres are manufactured using various raw materials such as sand, clay, calcite and colemanite. The variation in the amount of silica from sand or other raw material combinations determines the mechanical properties of the glass fibre (Mahltig & Kyosev, 2018).

The first documented use of glass fibre was in the 1st century BC when it was used by the Egyptians in their vessels and by Venetian glass makers decorating dishes. The use of glass fibre in the textile industry began about 1713 when Rene-Antoine Ferho de Reumur, a French physicist, started producing textiles (Martynova & Cebulla, 2018). He was able to recognise that fibre glass was pliable enough to be woven like a spider web. In 1842, the British developed a fabric from glass fibre. The manufacturing methods and quality of glass fibre greatly improved by the 1930s in the US and Germany. There are various glass fibres, as shown in Table 2; however, the E-Glass, a glass fibre used for electrical insulation, gave rise to the continuous fibre, which has become the global standard for general-purpose use. In 1935, the use of thermoset resins led to the development of fibreglass composites, which later on went on to be used in aircraft manufacturing during World War II (Martynova & Cebulla, 2018).

Glass fiber type	Silicon dioxides (SiO_2) (%)	Density (g/cm^3)	Tensile strength (MPa)	Modulus (GPa)	Elongation at break (%)
A-type	63–72	2.44	3300	72	4.8
C-type	64–68	2.56	3300	69	4.8
D-type	72–75	2.11	2500	55	4.5
E-type	52–56	2.54	3448	72	4.7
R-type	56–60	2.52	4400	86	5.1
S-type	64–66	2.53	4600	89	5.2
ECR-type	54–62	2.72	3400	80	4.3
AR-type	55–75	2.7	1700	72	2.3

Table 2: Types of glass fibres and their properties (Kiron, 2012)

2.3.2. Fibreglass Reinforced Composites

In general, composites mentioned in reference to fibreglass composites came into use and became popular post-World War II. The first known implementation of fibreglass composites for naval shipbuilding was by the Vosper-Thornycroft company in 1973. About 50 years before the commercial segment adoption of fibreglass composites, it was primarily used in defence and aeronautical applications. Because of its advantageous characteristics, it reached every market segment, from sports equipment to marine applications to construction (Rubino et al., 2020). The arrangement of fibre, the weave in the fibreglass fabric, is the primary determinant of the composite's strength and flexibility. The composite's strength is determined by the weight and weave of the fabric. Based on the weave or arrangement of fibre reinforcement in the required composite, a chop strand mat (see Figure 8) or woven roving (see Figure 9) fabric is used in combination with the epoxy resin (Corbin et al., 2020). Fibreglass sandwich panels with a polyurethane foam core (see Figure 10) are usually used where thermal insulation and strength are required (Rubino et al., 2020).



Figure 8: Chop strand Fibreglass mat (https://www.easycomposites.co.uk/)

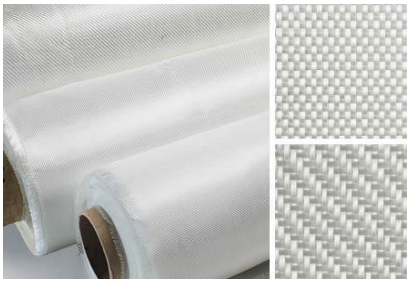


Figure 9: Woven Roving Fibreglass (https://www.easycomposites.co.uk/)



Figure 10: Fibreglass with Polyurethane core (https://www.composites.co.nz/flat-panels.html)



Figure 11: " La Chaise", fibreglass chair by Charles and Ray Eames(Pil et al., 2016)



Figure 12: Customisable, modular and transportable race car gaming simulator (https://www.easycomposites.co.uk/)



Figure 13: Fibreglass composite go kart body by MS fibreglass, Aotearoa New Zealand (*Go Kart bodies*, 2017)

The popularity of fibreglass composite use rose after world-renowned designers such as Charles and Ray Eames adopted and promoted the material in various products. The "La Chaise" (see Figure 11) is an excellent example of such a product that showcases the strength and complexity of fibreglass composite's potential. Fibreglass composites are cost-effective and used for products with high-strength complex shapes, as shown in Figures 12 and 13.

2.3.3. Fibreglass Composites in Boat Building

Marine products and offshore structures must withstand extreme environmental conditions, with boats specifically exposed to the corrosive nature of seawater. In comparison to traditional wood and metal boat building, as a corrosion-resistant material with structural strength characteristics, the use of fibreglass composites can lower production costs and reduce the weight of the product by 30% to 40% on average (Dokos, 2013; Rubino et al., 2020). Due to this weight reduction, the fibreglass composites industry claims it gives boats great mileage and a reduction in CO2 emissions, thereby becoming a greener alternative to wood and metal boats (Dokos, 2013; Rubino et al., 2020).



Figure 14: Custom Mini 2.4m Sailing Boat (https://www.easycomposites.co.uk/)

In shipbuilding, the hulls are made from a composite sandwich, a combination of fibreglass skins and a soft polymeric foam core, as shown in Figure 10. The sandwich material enhances the bending stiffness and the boat's resistance to shear and compressive forces. A combination of carbon fibre or Kevlar with cores like Nomex is used to build boats that require the best mechanical performance (Rubino et al., 2020). In general, smaller and medium-sized fibreglass boats (see Figures 14 and 17) have a panel thickness of 10 to 20 mm, and bigger boat panels, such as for yachts, are about 1-2 inches thick. Materials such as PVC also can be used as cores to improve damping. There are three main layers in the composite (Samson, 2023). The outer layer is the gel coat that gives the colour and acts as the first layer of protection from the water. This layer would be about 0.5 to 1 mm thick. The next layer would be the fibreglass fabric embedded with resin, which would be about 2 to 3 mm thick, giving strength and flexibility. The final layer is the structural layer, made again of fibreglass fabrics embedded in resin. This layer is traditionally made of multiple layers of biaxial fibreglass fabric or 1708 fibreglass, adding another 3 to 5 mm in thickness. Factors such as the ship's or boat's size, function, and the chosen manufacturing process decide the type and weight of the fibreglass fabric used (Samson, 2023).

The Visby Corvettes (see Figure 15) of the Swedish Navy are 72m long and 10.4 m wide, with a loading capacity of 620 tons, making them one of the longest ships constructed with fibreglass and carbon fibre composites. Their performance was surpassed by the Corvette patrol boats built by the Royal Singapore Navy, which are 80m long and have a loading capacity of 1016 tons. While the use of carbon fibre made the ships up to five times more expensive than those made with fibreglass composites, it also led to a reduction in hull weight by 30%, which resulted in substantial fuel savings (Rubino et al., 2020). Fibreglass composites are also used in submarines (see Figure 16) to construct specific structures like bulkheads and decks (Rubino et al., 2020).



Figure 15: Visby class corvettes of the Swedish Navy (Trevithick, 2019)


Figure 16: Submarine by Norco composites (NORCO, 2023)



Figure 17: A fibreglass composite boat by Rayglass, Aotearoa New Zealand boat manufacturer (Rayglass, 2020)

The marine industry and the fibreglass composites industry are highly interdependent. After the 2008 recession, there was a dip in the composites industry market due to the slowdown of the boat building industry. The slowdown was primarily due to changes in customer buying behaviour, which led to the closure of several smaller boat building companies. In 2011, the US led the boat market with a 50% market share, while 30 % belonged to Europe (Dokos, 2013).

2.3.4. Harmful Effects of Fibreglass Boat Building

A staggering 35 % of the ocean's microplastic pollution is directly contributed by boats and ships. Throughout a boat's life cycle, it keeps shedding microplastics made of paint binders, resin, and fibreglass into the water (Miller, 2023). Fibreglass propelled the boating industry to new heights; however, this has come at a significant cost. Old boats were dumped, and now, as the materials and composites used for these old boats break down, extremely harmful toxins and microplastics are continuously released into the oceans, harming marine life. Boats built in the 1960s to 1970s have started piling up in scrap yards. The older boats damaged (see Figure 18) due to harsh weather or hurricanes end up in landfills. These boats also used materials, paints and coatings that are now banned. For example, mercury-based compounds and tributyltin (TBT) used to be commonly used but are considered neurotoxins today. These types of pollutants have led to severe health impacts on humans, causing diseases like breast cancer and male infertility (Ciocan, 2020). It is also important to note that, in general, glass fibre has extreme effects on human skin and respiration. The

depolymerisation of the composite cannot be achieved easily due to how it is bonded to the medium, leading to the only cheaper solution of disposing it in a landfill (Bray, 2019).



Figure 18: Abandoned end of life Fibreglass boat decomposing (Miller, 2023)

Some studies show the direct impact of fibreglass on oysters. Micro strands (see Figure 19) from reinforced glass plastics were found in oysters. These micro-strands can cut through the organism's flesh and stay embedded, further developing into cancerous tumours. There are no standardised regulations to enforce the recycling and proper disposal of end-of-life boats (Hodgetts, 2022). In the past decade, the Chichester Harbour Conservancy in UK, noticed an increase in the number of dying oysters along with a lack of healthy oysters captured. This shortage of oysters led to the closure of this conservancy in 2018. This decline was found in oysters, shellfish, water fleas (see Figure 20), and other animals. A surprising discovery was the tiny “mystery shards”, later identified as fibreglass shards, embedded within the marine life. The fibreglass shard concentration was as high as 7000 micro hair-like shards in 1kg of oyster (Miller, 2023).

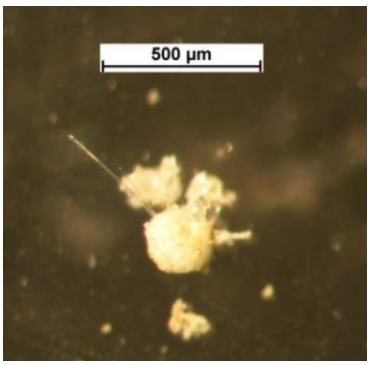


Figure 19: Identified fibreglass embedding (Hodgetts, 2022)



Figure 20: Fibreglass strand and resin surrounding a Water flea (Miller, 2023)

As shown in Figure 21, there are a few processes like crushing, burning, pyrolysis (thermal cracking of chemicals at 450 to 700 °C), and solvolysis (substitution reaction using solvents) that can be used to recycle or reclaim some of the material in the composites; however, the proper recycling and disposal of vessels is expensive and often avoided (Bray, 2019).

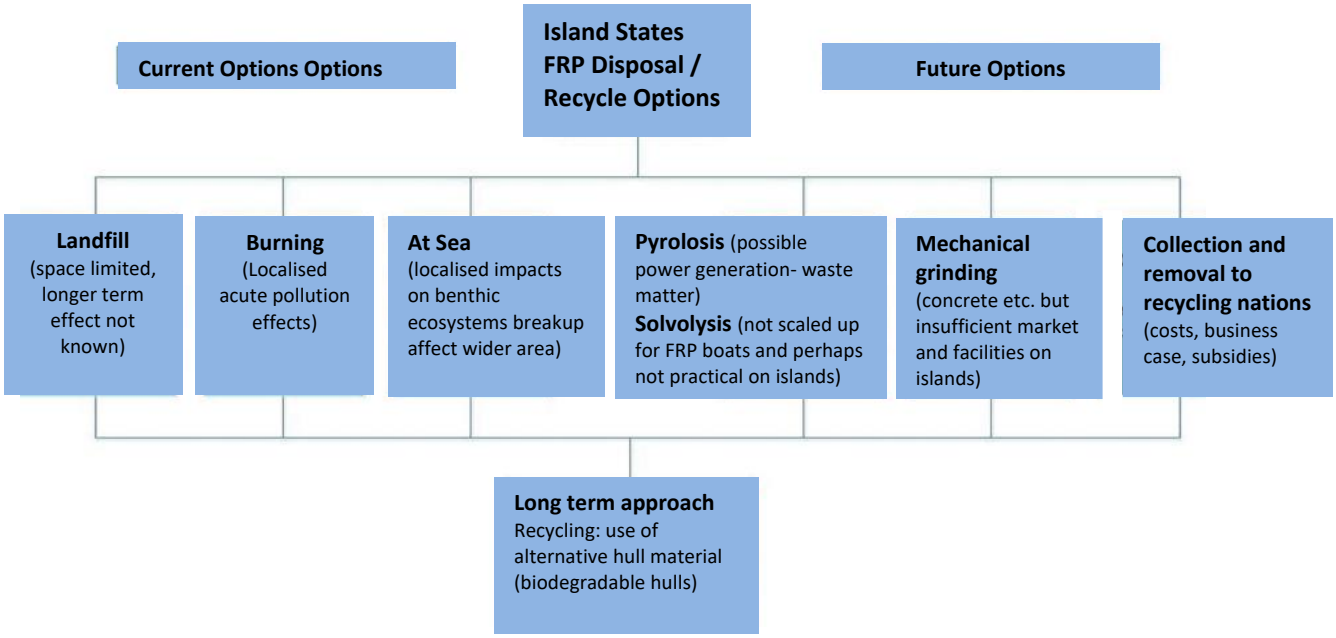


Figure 21: FRP Vessel disposal and management concept for current and future scenarios (Bray, 2019)

Even if these processes were to be used, offsetting harmful gases becomes another issue. Open burning of fibreglass produces high amounts of VOCs (volatile organic compounds), SVOCs (Semi VOCs) and PAHs (Polycyclic Aromatic Hydrocarbons) (Bray, 2019). The cost economics of recycled fibreglass (made from crushing fibreglass into smaller fragments) is also not encouraging as the market is too small. On average, Fibre reinforced plastic (FRP) composite boats have a life expectancy of 30 to 50 years, and the issue of responsibly disposing of them has been a problem since the 1980s. There are regular discussions in NZ about imposing an eco-tax on older boats but so far, any serious attempts have failed as such a tax was found to be too impractical to implement (Bray, 2019).

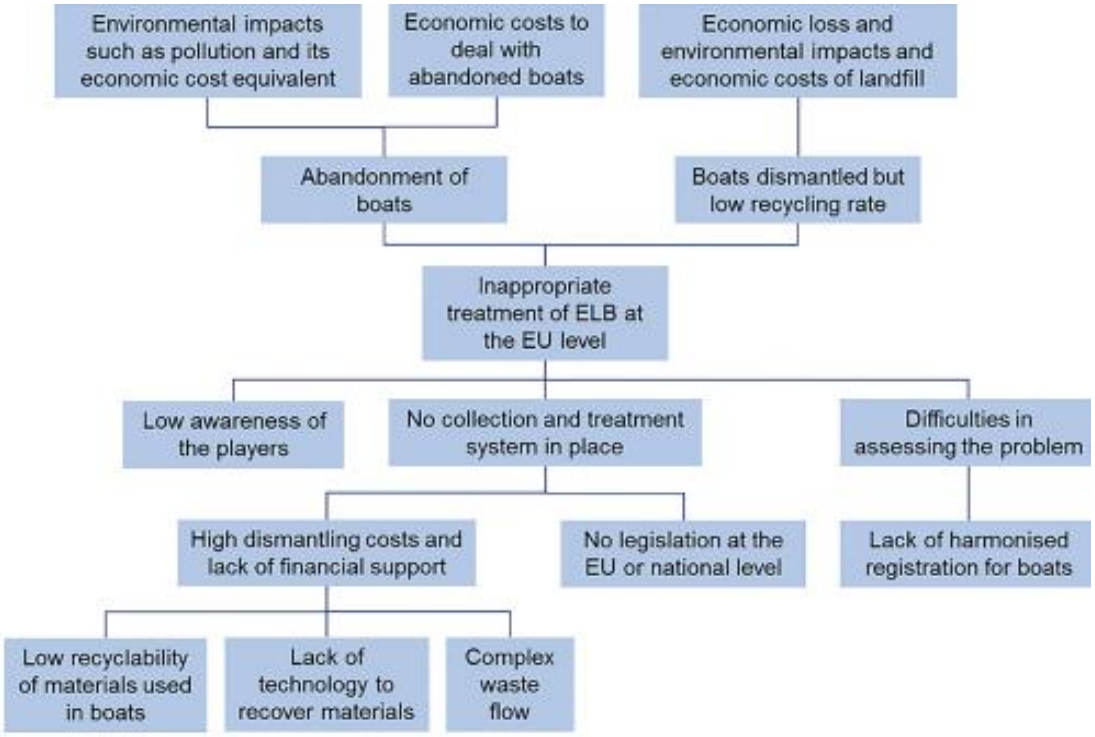


Figure 22: ELB (end-of-life boats) management of boats in an EU (European Union) specific project (Bray, 2019)

These harmful effects of FRP composites are one of the reasons that this thesis is looking at natural fibre-based bio-composites as an alternative to fibreglass composites, along with the fact that they are the most popular and viable alternative. Figure 22 provides an overview of how end-of-life boats (ELB) are disposed of in the European Union in the context of a project reporting on the management of boats. The boat building industry and the fibreglass composites industry generally have a long way to go with respect to the recycling and disposal of ELB.

2.4. UNDERSTANDING NATURAL FIBRE COMPOSITES

There is a demand for natural fibre composites (NFC), with most NFCs using subsidised flax as the primary raw material (Karus & Vogt, 2004). The use of NFC has been increasing since the 1990s. The lower weight distribution and relative characteristics to Fibreglass reinforced composites are the primary reasons for the recent adoption of NFCs (Fike, 2016). Natural fibres are derived from animals, vegetables, and minerals like asbestos (see Figure 23). Reinforcements in NFCs are majorly extracted from bast fibres derived from plants like flax,

hemp, kenaf, and jute (see Figure 24). They can also provide other natural derivatives such as lignin or wax (see Table 3). The main reason for using bast fibres is that they are very strong, evident in the strength and support they provide in growing plant (Elseify et al., 2021; Stokke, 2013). Compared to other vegetable fibres, hemp fibres are comparatively more robust and stiffer, making them an excellent competitor for NFCs (Graupner et al., 2022). Young's modulus measures a material's stiffness by quantifying how it deforms under stress. While flax may have a higher tensile strength, hemp's Young's modulus is twice as that of flax, as shown in Table 4 (Castegnaro et al., 2017), indicating hemp is stiffer and less prone to deformation, making it more suitable for applications requiring rigidity and stability. It should be noted that the flax fibre referenced throughout this document refers to linen flax (Linum usitatissimum), not Harakeke or New Zealand Flax (Phormium tenax).

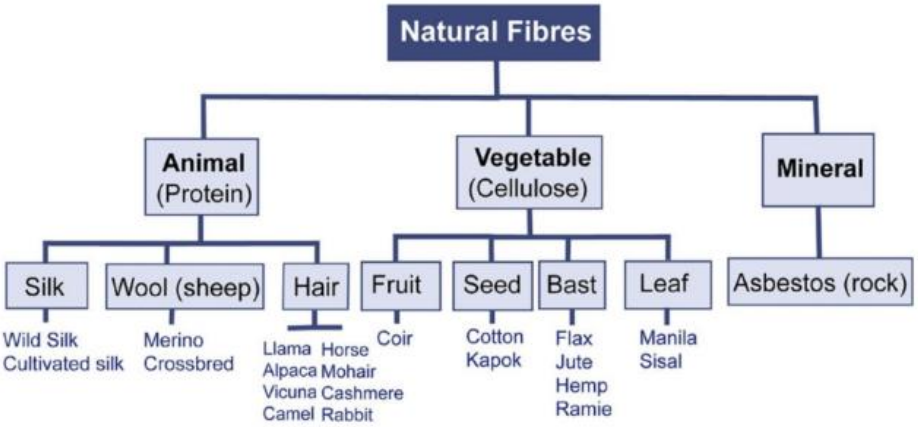


Figure 23: Types of Natural fibres (Shekar & Ramachandra, 2018)

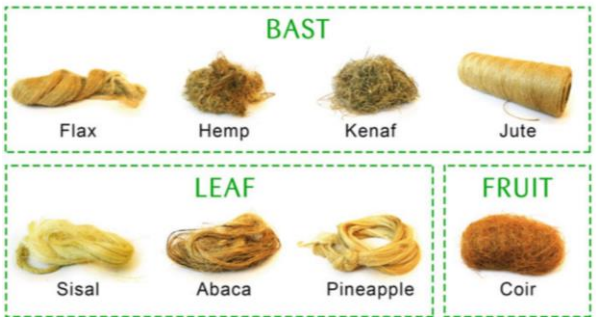


Figure 24: Vegetable fibres commonly used by the automotive industry for composites development (Elseify et al., 2021)

Fibers	Cellulose (wt.%)	Hemicellulose (wt.%)	Lignin (wt.%)	Pectin (wt.%)	Wax (wt.%)	Moisture content (wt.%)
Flax	71	18.6–20.6	2.2	2.3	1.7	7–10
Hemp	70.4–74.4	17.9–22.4	3.7–5.7	0.9	0.8	8–11
Jute	61–71.5	13.6–20.4	12–13	0.2	0.5	10–14
Ramie	68.6–76.2	13.1–16.7	0.6–0.7	1.9	0.3	7–15
Kenaf	35–57	21.5	15–19	3–5	-	6–12

Table 3: Chemical composition of bast fibres (Al Faruque et al., 2022)

Table 2
Mechanical properties of natural and synthetic fibre [6–24].

Fibre	Density (g/cm^3)	Length (mm)	Failure strain (%)	Tensile strength (MPa)	Stiffness/Young's modulus (GPa)	Specific tensile strength ($MPa/g\ cm^{-3}$)	Specific Young's modulus ($GPa/g\ cm^{-3}$)
Ramie	1.5	900–1200	2.0–3.8	400–938	44–128	270–620	29–85
Flax	1.5	5–900	1.2–3.2	345–1830	27–80	230–1220	18–53
Hemp	1.5	5–55	1.6	550–1110	58–70	370–740	39–47
Jute	1.3–1.5	1.5–120	1.5–1.8	393–800	10–55	300–610	7.1–39
Harakeke	1.3	4–5	4.2–5.8	440–990	14–33	338–761	11–25
Sisal	1.3–1.5	900	2.0–2.5	507–855	9.4–28	362–610	6.7–20
Alfa	1.4	350	1.5–2.4	188–308	18–25	134–220	13–18
Cotton	1.5–1.6	10–60	3.0–10	287–800	5.5–13	190–530	3.7–8.4
Coir	1.2	20–150	15–30	131–220	4–6	110–180	3.3–5
Silk-	1.3	Continuous	15–60	100–1500	5–25	100–1500	4–20
Feather	0.9	10–30	6.9	100–203	3–10	112–226	3.3–11
Wool	1.3	38–152	13.2–35	50–315	2.3–5	38–242	1.8–3.8
E-glass	2.5	Continuous	2.5	2000–3000	70	800–1400	29

Table 4: Natural fibres and E-glass, mechanical properties (Pickering et al., 2016)

This study focuses on hemp fibre as the contending natural fibre that could replace fibreglass in Aotearoa New Zealand's composites industry.

2.4.1. Industrial Hemp – The Multifaceted Crop

Hemp has been one of the most valuable crops throughout the history of humanity. It is thought to have originated in Eurasia but has since spread across the globe (Fike, 2016). There is a well-documented history of industrial hemp's cultivation as a crop for various uses, especially for its seeds, oil, and clothing (Schluttenhofer & Yuan, 2017). In fact, the first known copy of the printed Gutenberg bible was on paper made from hemp (Sen & Reddy, 2011). It has been known to be cultivated in China since 2,800 BC. There is no documentation of the crop ever becoming a weed; instead, it is known to stop the growth of other weeds, and it has very few diseases or pest issues (Sen & Reddy, 2011).

Hemp can grow up to 5 meters in height, and its root system can reach about 2.5 meters in depth (Merfield, 1999). The male plant tends to have fewer leaves, appears thinner, and has more fibre than the female plant (see Figure 25). Hemp produces sturdy stalks, which is the primary source of fibre, with diameters ranging from 2.5 to 5 cm. They should be grown in

higher latitudes for the best yield, as growing hemp near the equator can lead to lower fibre and lesser grain. The best yields seem to be in climate conditions with temperatures between 15 °C to 27°C. The crop requires drained soil with good fertility, similar to those found along freshwater bodies (Fike, 2016). The hemp crop takes about 100 to 130 days on average to reach the harvest phase. The crop can be harvested about 3- 4 times a year, making it one of the few crops with such multifaceted use and recurring harvest (Darby, 2021). Another reason for its environmentally friendly tag is the minimal artificial fertiliser requirement to grow the crop. This makes hemp one of the few crops that can produce sizable yields and grow sustainably without using insecticides and fertilisers. A hectare of farmland, on average, produces 3.5 tons of industrial hemp in 100 days (Darby, 2021).

Hemp can generate a higher yield when compared to flax (Sen & Reddy, 2011). As an alternative to cotton, hemp is proving to be an excellent sustainable option due to its high fibre yield and lower requirements of nutrition or water (Cerri et al., 2023). When compared with cotton clothing, hemp clothing has 95% more UV protection and uses 1/6th of the water to grow (Jordan, 2014).



Figure 25: The plant on the left is the male, and the one on the right is female. (Small et al., 2002)

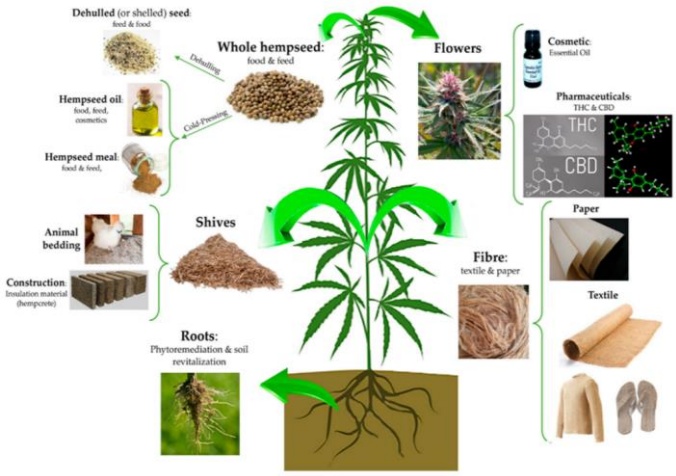


Figure 26: The various raw materials and products created from industrial hemp (Kaur & Kander, 2023)

Amongst natural fibres, hemp produces some of the strongest fibres (Pil et al., 2016). The male plant of the crop tends to have a better fibre quality. The fertilisation and sowing density conditions influence the quantity and property of the bast fibres extracted from the plant (Cerri et al., 2023; Schluttenhofer & Yuan, 2017). On average, the plant's bast fibre

contents account for 38.7% of the yields, about 20 to 30% of the plant's fibre content (Darby, 2021). Modifying agronomic practices can help achieve suitable fibre and lignin quantity and quality. Hemp produces two types of fibres, primary and secondary (see Figures 27, 29, and 30). The plant's sex plays an important role in the quality of the primary fibre. The primary fibres are about 20 to 100mm long and are used in textiles, whereas the secondary fibres are about 2mm long (Cerri et al., 2023).



Figure 27: Hemp stem with bast fibre exposed from under bark (Fike, 2016)

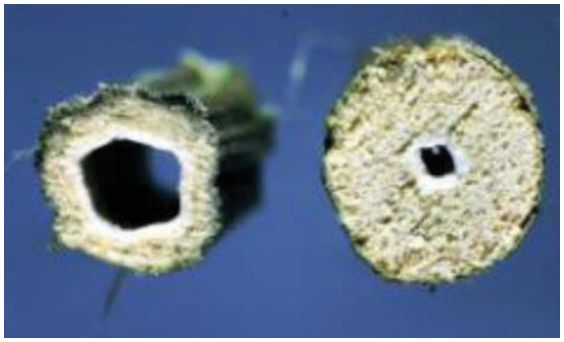


Figure 28: Cross-section comparison of Marijuana stem (left) vs industrial hemp stem (right) (Fike, 2016)

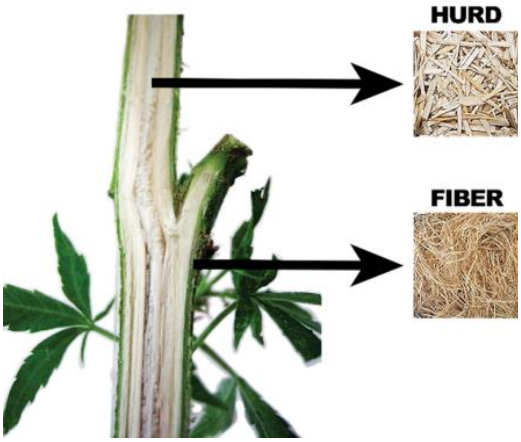


Figure 29: Commonly used bi-products from Hemp for composites (Kaur & Kander, 2023)

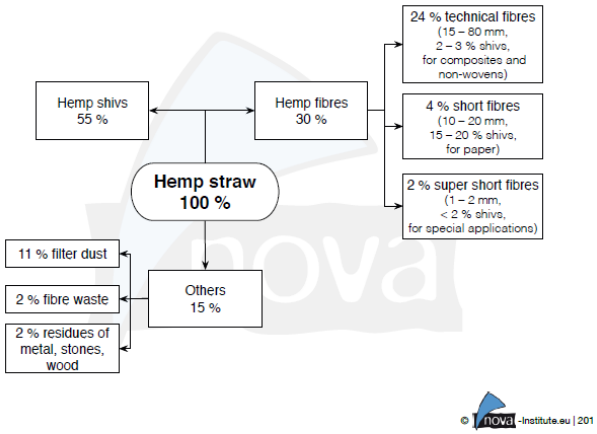


Figure 30: The various product outputs in Hemp fibre production (Barth & Carus, 2019)

Since ancient times, hemp fibre has played a significant role as a valuable textile resource in rope and industrial-scale canvas used in various industries (Pil et al., 2016). During the 1600s in colonial America, it was the most sought-after raw material for making ropes; in the 1700s, hemp canvas became commonly used for sails of England's naval vessels (Fike, 2016). Currently, it is being used in plastics, 3D printing and production of carbon nanosheets (Schluttenhofer & Yuan, 2017).

A significant advantage of growing hemp for its fibre is its immense environmental benefits. Its sustainability capabilities are owed to its biological origin and carbon sequestration

during growth (Graupner et al., 2022). A hectare of industrial hemp can absorb about 2.5 to 4 times CO2 compared to forests. Not only does the cultivation of hemp create a carbon sink, it also helps to restore soil health (Vivek, 2022).

Industrial hemp is a non-psychotropic crop containing less than 0.2% of Tetrahydrocannabinol (THC) level, a psychoactive compound (Müssig et al., 2020; Schluttenhofer & Yuan, 2017). It belongs to the same Cannabis Sativa species as the narcotic crop marijuana. However, unlike industrial hemp, marijuana (Figure 28) contains much higher levels of THC. Hemp can, however, be used to disrupt marijuana production when hybridised. Though hemp has a rich history of use and well-established archaeological records, its downfall began in the late 1800s. This drop in usage was mainly due to more affordable alternatives and the technological advancements of that period (Merfield, 1999). In effect, hemp production as a cash crop in the US fell due to its inability to compete with cotton, jute, and abaca fibres.

Furthermore, the adoption of steam engines to power ships ended the demand for hemp canvas sails (Fike, 2016). Ultimately, the introduction of the US Marijuana Tax Act in 1937 was the axe that fell the crop's future, eventually making it illegal to produce hemp due to its association with marijuana. Fortunately, there was a resurgence of industrial hemp use in the 1980s, as several countries gave it legal status, boosting their economies (Merfield, 1999). Over the years, American entrepreneurs and businesses have been importing hemp from China, Eastern Europe, and Canada (Darby, 2021). These countries are actively involved in the hemp industry, and smaller countries like Aotearoa New Zealand are also positioning themselves strategically to capitalise on the strength and niche product segment offerings. Israel and the Australian state of Victoria are focused on healthcare pharmaceutical products extracted from hemp, while Canada focuses on the hemp fibre market covering textiles and construction (Marsh, 2020). Thus, hemp is claiming its once-lost status as a lucrative cash crop, bringing in market opportunities and product offerings (Darby, 2021). Industrial hemp is gaining popularity and is farmed in Aotearoa New Zealand in several regions like Auckland, Northland, Waikato, Bay of Plenty, Wellington, Manawatu-Whanganui, Taranaki, and the South Island (Marsh, 2020).

2.4.2. Hemp Fibre Composites

The manufacture of hemp fibre is different to most natural fibres. While the machinery and processes used are similar to those used to produce flax fibre, the spinning and weaving processes are skipped for composite applications based on fibre production (see Figure 31). The main drawback of using industrial hemp for its fibre was the expensive traditional retting process used to extract the long fibres. Recently, new technology has brought a fresh appeal to manufacturing products, focusing on the reinforcement abilities of hemp fibre in plastics (Fike, 2016). Hemp fibres are used in composite products for insulation and door panelling due to their higher strength. Though there is a high potential for use in mass paper pulp manufacturing, it is not yet competitive compared to regular paper from wood pulp (Small et al., 2002). A 1938 article in the magazine- popular mechanics, (Schluttenhofer & Yuan, 2017) claimed that about 25,000 products could be made using hemp (see Figure 26), from paper to nano fibres and reinforced plastic.

Hemp Fibre production for composites

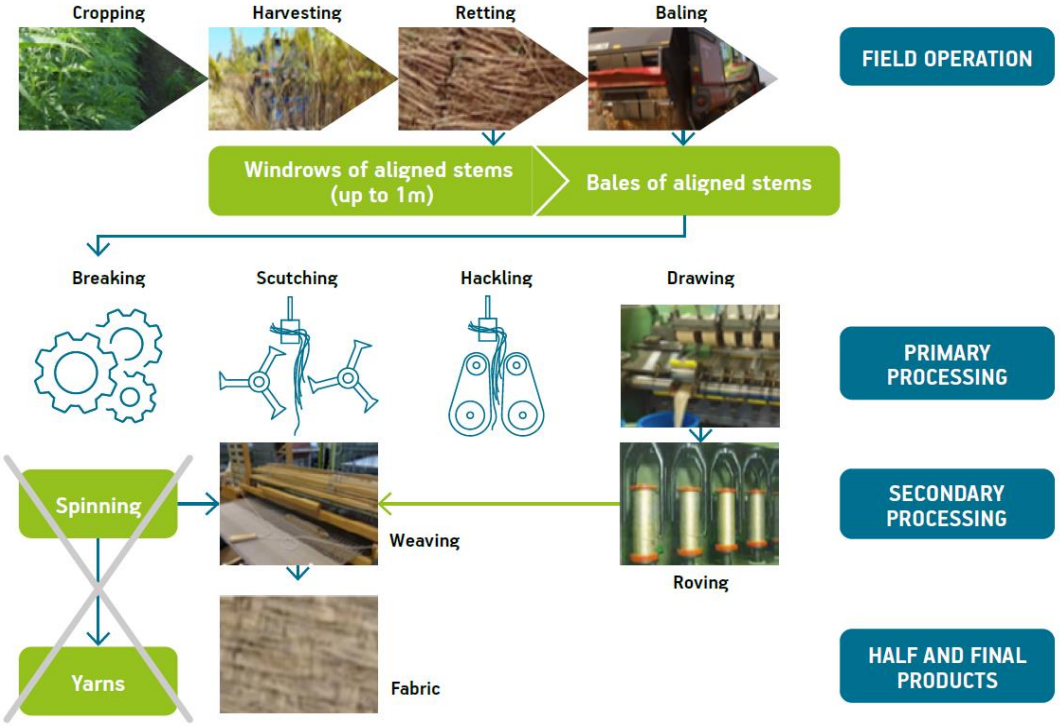


Figure 31: Hemp fibre production process (adopted from the Flax production chain) (SSUCHY, 2020)

This growing trend of using bio-composites made from bio-based plastics matrices (Faruk et al., 2012a) has led to the use of hemp fibre composites in speciality products, especially in the automotive (see Figures 39,43, and 44), furniture, and architecture sectors. Due to

hemp's low environmental impact together with its performance enhancing properties, products such as surfboards and sound speakers makes it a popular choice among product designers (see Figures 32 and 33). Products such as the “Hemp Chair” by Werber Aisslinger showcase the blend of industrialisation and the designer’s craftsmanship. It promotes the use of natural materials for sustainability and carbon offsetting (Pil et al., 2016).



Figure 32: Hemp Chair (Aisslinger, 2015)



Figure 33: Hemp surfboard by SOLID (O’Hara, 2021)

NFC’s future is promising, primarily due to two key contributing factors: its ability to be environmentally sustainable and technically uncompromising on performance. For non-structural composites, it is the short bast fibres of hemp that have always been in use; however, now there is growing demand for hemp composites in products that are performance dependent (Müssig et al., 2020) and as a promising material in certified aviation (Scarponi & Messano, 2015). According to the German Aerospace Centre, composites made from hemp-based polymers tend to perform better (see figure 34) than other fibres and demonstrate similar characteristics to fibreglass composites in certain aspects (Fike, 2016).

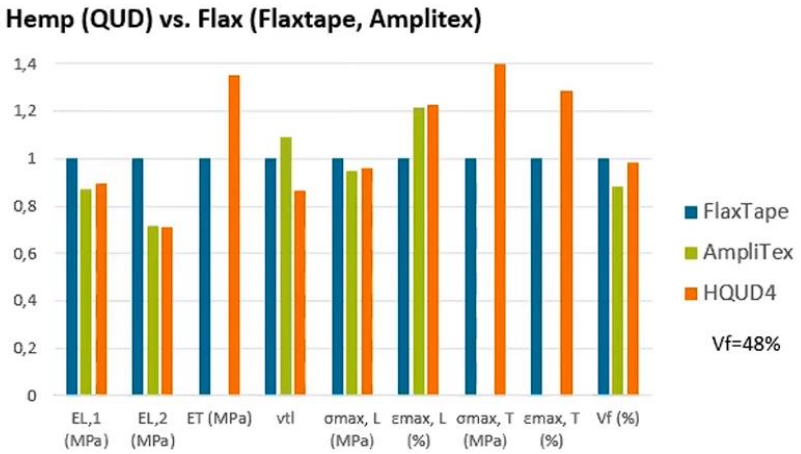


Figure 34: Comparison of Hemp fibre reinforced composites (bio-epoxy based) with other natural fibre brand composite products in the market (SSUCHY, 2022b)

In general, NFCs have a remarkable ability to dampen vibration, making them an obvious choice for products in the sporting and music industries. Speakers using cones made from Flax or hemp tend to provide a homogenous sound with superior dynamics (Pil et al., 2016). Nathan Armstrong, the director and president of Motive Industries, mentions in an interview how the 1st prototype - Model T, developed by Henry Ford in 1941, had hemp composite body panels and ran on hemp oil (see Figure 40). Hemp has become popular in architecture where it is used to make hempcrete (see Figure 45), a building construction material. A 15th-century bridge (see Figure 46) that was made with hempcrete still stands today (Davis, 2020). There is evidence that hemp was used in the 2nd century BC to 6th century AD for the construction of what is now a UNESCO heritage site - the Ajanta and Ellora cave temples (see Figure 47) in Maharashtra, India, that also contains several Hindu and Buddhist religious artifacts (Singh & Sardesai, 2016). The potential for use of hemp within the plastics industry for 3D printing (see Figure 35), injection moulding (see Figure 36), and architecture (see Figures 37, 38, 41, and 42) is promising (*Hemp Plastic*, 2023).



Figure 35: 3d printing with Hemp PLA (*3D printing with Hemp*, 2023)



Figure 36: Hemp plastic pellets available for injection moulding in Hemp Polyethylene (HDPE) or Hemp ABS. Both materials contain 25% hemp particulate (*Hemp plastic*, 2023)

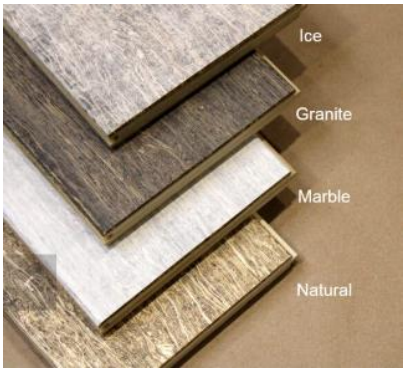


Figure 37: Hemp wood flooring boards available in various colours and textures (*HempWood Natural Flooring*, 2020)



Figure 38: Hemp wood lumber (*HempWood Lumber- An American Innovation*, 2020)





Figures 39 & 40: Natural fibre composites, including hemp, used in the Mercedes Benz C class (left) and Henry Ford demonstrating the strength of the hemp biocomposite panel trunk door of the 1st prototype car made from hemp and bio-resins from soy (Right) (Small et al., 2002)





Figures 41 & 42: Hemp wool used for insulation (left) and a medium-density hemp fibreboard (right) (Small et al., 2002)





Figures 43 & 44: Lotus Elise with hemp composite panels and seats (Read, 2008)



Figure 45: Hemp house constructed using " Hempcrete" (HBANZ, 2023)



Figure 46: Sarthe River Bridge in Saint Céneri le Gérei, France, is made using a composite of hemp and limestone (Cannalore, 2018)

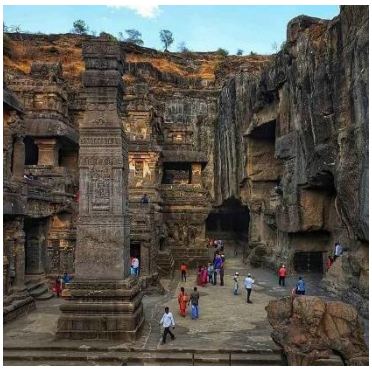


Figure 47: Ajanta and Ellora caves, India (Dsouza, 2023)

In general, NFCs have increased damping ability and bending strength, specifically, hemp fibre composites have a lower density, higher specific bending stiffness, and impact strength. A tensile strength of 550- 900 Mpa makes hemp fibres a valuable resource for developing composites. The bonding between the fibres and polymer matrix is essential to achieve a composite with performative mechanical strength (Sen & Reddy, 2011). In NFCs, the weave of the fibre used as reinforcement for the fibre can be uni-directional, non-woven or woven. The type of weave used will be based on the product application. It is best that the yarn twist in the fabric used, particularly for composite manufacturing, remains low; this will help improve resin penetration. Standard flax fibre composites usually have flax fibres with low twisted roving (Corbin et al., 2020).

Unlike synthetic fibres, hemp fibres are manufactured with minimal hazards, produce extremely low toxic fumes on heat exposure and cause less abrasive processing equipment damage, making them a more affordable and sustainable choice (Pickering et al., 2016). A 100% bio-composite can be developed by incorporating natural or complete bio-resins with aligned long fibres. Biopolymers like PLA (polylactic acid derived from sugar cane or corn)

and other cellulose-based polymers are preferred to create a complete biodegradable composite (Shekar & Ramachandra, 2018).

Compared with fibreglass composites, hemp composites manufactured using a sheet moulding compound (SMC) are better suited for interior panelling in automobiles due to their higher mechanical properties (Lee et al., 2005). Besides the lower costs, hemp composites are preferred because they provide better acoustics and vibration damping (Pil et al., 2016). The lower density of hemp fibres and comparable stiffness to glass fibre give it a higher specific stiffness in tension and bending. With a 2.5 times higher vibration-damping capacity than carbon fibre composites, hemp composites have become a natural choice for vehicle interior panelling (Pil et al., 2016).

Despite their many benefits, hemp fibre composites also have certain disadvantages, the most common being their hydrophilic nature and issues with their interfacial bonding (Asyraf et al., 2022). Its hydrophilic nature gives it a moisture-absorbing characteristic that reduces its strength. And, as a natural fibre, there can be variability in each fibre strand's properties. Compared with fibreglass composites, they tend to have lower durability, though this can be changed when processed with the proper chemical treatment (Pickering et al., 2016). Chemical treatments can increase the strength of these natural fibres, making them suitable for structural use (Shekar & Ramachandra, 2018). The performance of hemp composites is primarily dominated by the fibre bundle ratio. The retting and fibre extraction processes also can affect the fibre's quality. When decortication is done less aggressively, the fibre quality from the bast becomes better. Hence, a gentler decortication process can achieve a higher quality of bast fibre. It is essential to have low-twist roving and yarn in the textiles developed for composites (Müssig et al., 2020). With the correct extraction and processing of the fibre, the hemp composite can outperform aluminium steel and fibreglass composites with respect to specific bending stiffness. In composite applications, the essential requirement is the composite's stiffness, not the strength (JEC, 2022).

Hemp is comparable to flax as a reinforcement, however, the most common natural fibre used as reinforcement for composites is flax. This is mainly due to the lack of access to hemp fibre as a raw material. Gurit, a company in Aotearoa New Zealand, launched its range of natural flax fibre composite products in collaboration with a Swiss startup – Bcomp. The

composites also use bio resins as the medium for the flax reinforcements (*Reinforcements*, 2023). The impact strength of flax with glass fibre reinforced PP composite hybrids was greatly improved by switching the natural fibre from flax to hemp. In a hybrid PP composite of hemp and glass fibre reinforcement, the impact strength was at 75 J/m^2 (Satheeshkumar & Jesuarockiam, 2014). Amongst hybrid composites, the potential of hemp glass hybrid composites is promising as it offers improved stiffness and damping characteristics (Graupner et al., 2022). The Hemp fibre fabric weave pattern determines the strength of the composite and the purpose of use. Hemp fabric with the satin weave of warp density at 6 yarns/ cm and weft density of 9.5 yarns/cm, as shown in Figure 48, proved to be a good selection for developing performance-based hemp fibre reinforced composites. The rovings have a linear density of 259 Tex and a twist level of 36 turns/m and were chemically treated in the mercerisation process to increase their tenacity (Corbin et al., 2020).

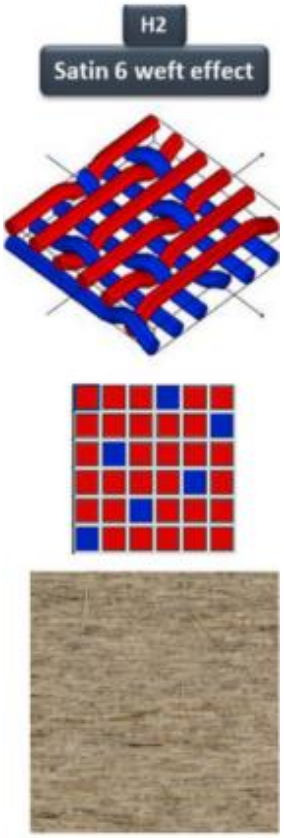
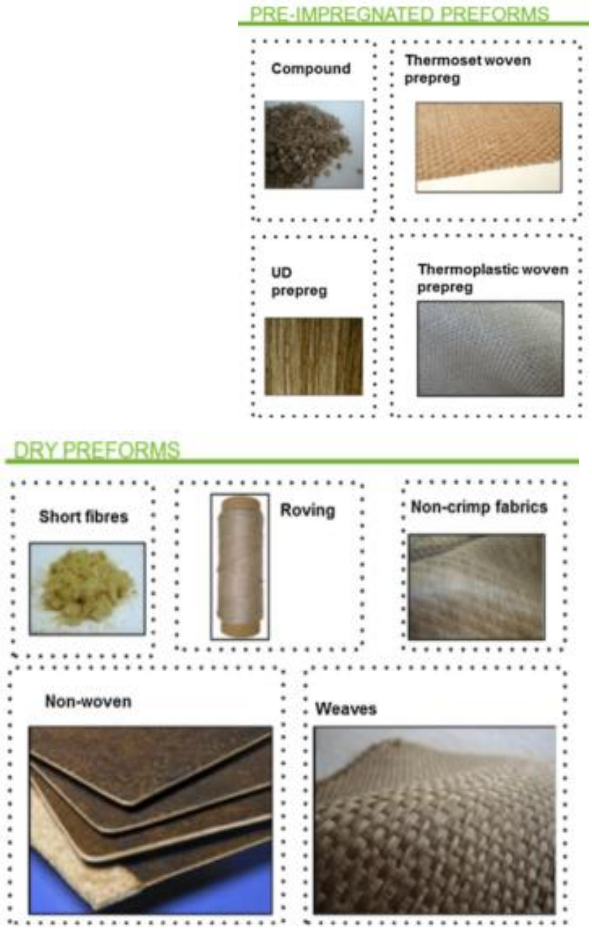


Figure 48: The satin 6-weft effect with the most promising weave pattern for Natural fibre composites (Corbin et al., 2020)



Figures 49 & 50: Prepreg preforms (resin or glue-infused fibre) (above) and dry preforms fibres (below) made from natural fibres like flax and hemp (Pil et al., 2016)

The level of twist (i.e., number of turns per meter) in the roving influences the strength and mechanical properties of the final composite. Mechanical stress direction was better in low twist-level rovings (see Figure 51) (Placet, 2022). This also allows for the fibres to be more parallel and allows for better resin penetration (Lu et al., 2022). Prepreg natural fibre preforms are also increasing in demand, with various weaves and non-woven (see Figure 49 and 50) options available.



Figure 51: Low-twist hemp rovings for composites reinforcement fabric weaving (SSUCHY, 2020)

Companies such as Bcomp have been manufacturing bio-composites using flax as the natural fibre reinforcement. Although their flax composites have performed as well as, if not better than, fibreglass composites, the company was dissatisfied with the use of resins that were fossil fuel-based embedding matrices. They have partnered with several research institutes to develop a natural or lignocellulosic, non-petroleum-based resin to replace their current epoxy resins (Mathijsen, 2021). Monophenolic compounds can be extracted from hemp hurds or birch bark through a catalytic fractionation, which can be converted to monomers and polymers using green chemistry. Thermoset resins developed by SSUCHY are believed to have the potential to replace (see Figure 52) petroleum-based matrices. Though not recyclable or biodegradable, they have the required mechanical properties when compared to fossil-based polymer resins (SSUCHY, 2022a)

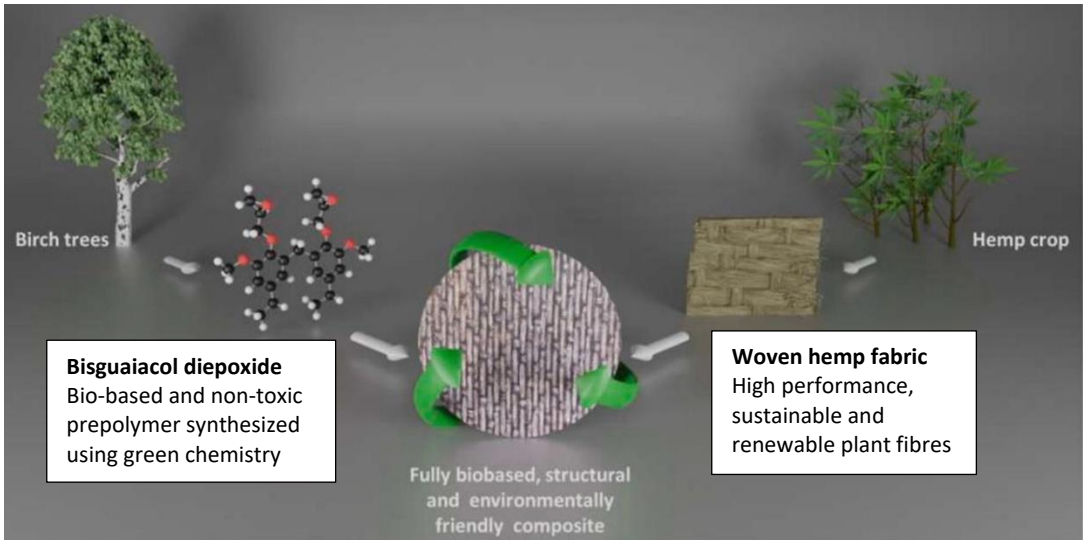


Figure 52: Manufacturing of High bio-based composites with Bio resins processed and processed using birch tree bark (Witthayolankowit et al., 2023)

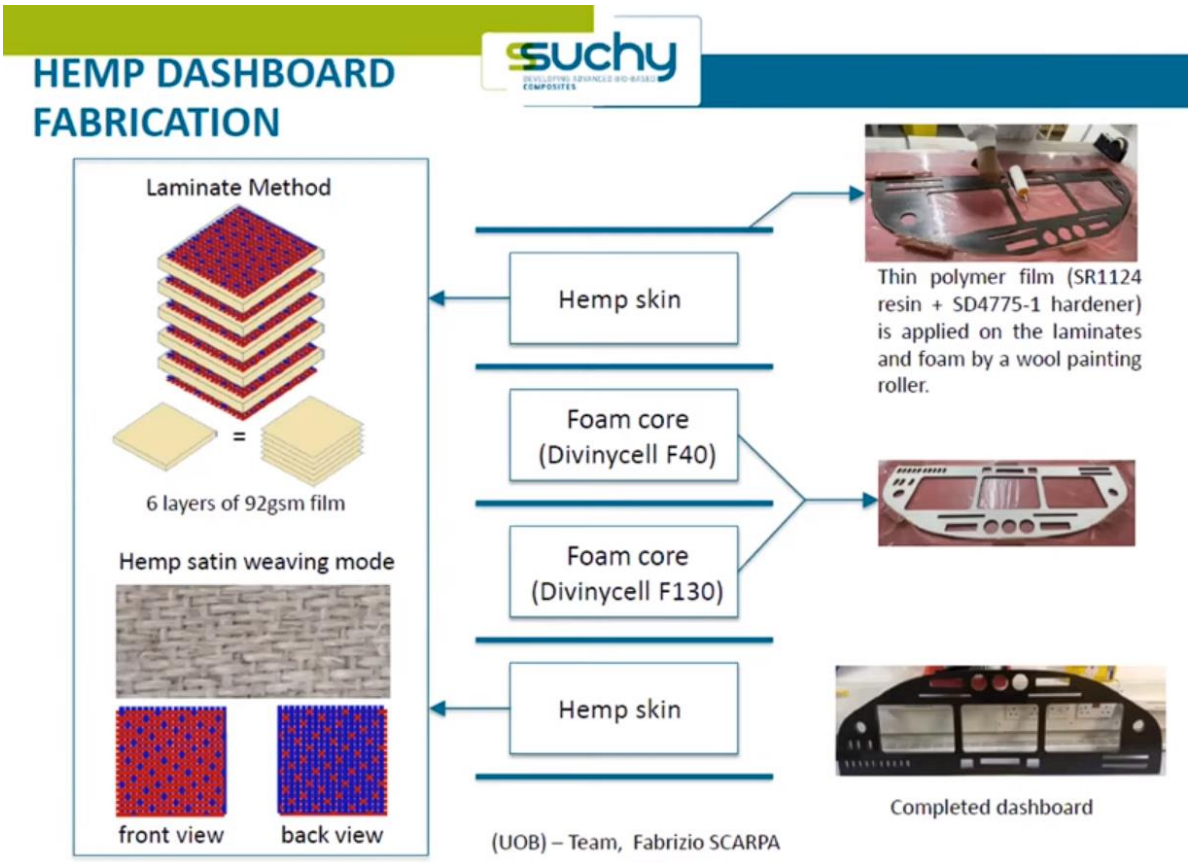


Figure 53: A hemp dashboard for aircraft cockpit (SSUCHY, 2022b)

Team SCARPA has designed and built an aircraft cockpit (see Figure 53) from hemp fibre reinforcement and foam cores. Though this is not entirely biodegradable, it showcases the potential of hemp fibre composites (SSUCHY, 2022b). Specific new compositions of fully biodegradable composites are being experimented with. For example, Ecovative Design, a US material development startup, has created mushroom-based composites that use hemp hurds as the binding material (see Figure 54). These composites are used in packaging with a short life span (Karana et al., 2018) and have also been experimented with to make a canoe (see Figure 55). BioFab, a Aotearoa New Zealand-based startup, has licensed the technology from Ecovative Design to develop mycelium-based composite products for Australasia. There is potential to use Mycelium and saw dust composites as an alternative to Polyurethane Foam (PU Foam). Mycelium composite has been shown to absorb more energy from high impact compared to PU foam. However, the mycelium composites deformed and failed faster on low energy impacts when compared to PU foam (Miralbes et al., 2021). In boat building and the construction industry, PU foam is commonly used with

fibreglass laminate to create a sandwich core to increase the strength of boat structures or wall panels.



Figure 54: Mycelium composite packaging for perfume bottles by Bio Fab, Aotearoa New Zealand (*Mushroom Packaging*, 2020)



Figure 55: Myconoe: The mushroom boat, developed by Katy Ayers, tested on a Nebraska lake. (Kuta, 2020).

PLP Labs has created a bio-composite using mycelium and 3D Printed wood-based PLA to prototype building blocks (see Figures 56 and 57). The PLA acts as the nutrition medium and the structural map for the mycelium to grow. The company follows symbiotecture, based on Symbiocene principles (designing and replicating the symbiotic processes found in nature) (*Symbiocene Living*, 2021).





Figures 56 & 57: Mycelium blocks (Left) and Bio-based organic form using Mycelium (*Symbiocene Living*, 2021)

2.5. COMPARATIVE ANALYSIS OF FIBREGLASS COMPOSITES VS HEMP REINFORCED COMPOSITES

One of the main disadvantages of fibreglass composites is the high raw material costs of fibreglass and resins. Compared with aluminium boats, the mould and tooling costs are much higher for composite boat building, which makes the capital required to start a composite boat building business higher (Dokos, 2013).

The most significant disadvantage is the recyclability issue of fibreglass composites. Globally, new regulations are being put in place for recycling composites. However, fibreglass recycling is still in its infancy (Dokos, 2013).

	Fibres	
Properties	E-glass	Hemp
Density g/cm^3	2.55	1.48
Tensile strength (MPa)	2400	550–900
E-Modulus (GPa)	73	70
Specific (E/d)	29	47
Elongation at failure (%)	3	1.6
Moisture absorption (%)	–	8

Table 5: Comparison of the properties of Glass fibre vs hemp fibre (Wambua et al., 2003)

The negative impacts that synthetic and fibreglass-reinforced composites have caused far outweigh the positives they have contributed. Its contribution to CO2 emissions and toxicity from its inability to decompose has made us seek other biodegradable options. Natural fibres like hemp, being biodegradable, are apparent contenders for green alternatives (Elseify et al., 2021). From Table 5, it is evident that hemp fibre has certain advantages over fibreglass when it comes to the environmental impact of the products. When comparing the properties of replacing glass fibre composites with hemp fibre-reinforced polypropylene (PP) composites, it results in a 3-ton reduction in CO2 emissions per product. Using starch-based bioplastics like polylactic acid (PLA) and polyhydroxyalkanoate (PHAs) for hemp composites may be a promising option to decrease reliance on fossil fuels and reduce environmental impact. Specifically, PLA has received a lot of attention as a key component of the matrix material for bio-composites (Faruk et al., 2012b). Hemp fibre PLA composites with 30wt% hemp fibre showed a 100% increment in Young's modulus and a 30% increase in tensile strength (Ahmad Sawpan et al., 2007). In Aotearoa New Zealand, an inventor, Logan Williams, has developed a material called "Keravos", which is made from a PLA and wool mix, that was used to develop a catamaran. Using this new material meant that the boat needed 40kg of plastic less than normal (Boswell, 2021).

2.5.1. Environmental Impact

For every tonne of glass fibre manufactured, about 1.7 to 2.5 tonnes of carbon dioxide (CO2) is released. In comparison, natural fibres produce about 0.35 to 0.55 tonnes of CO2 (0.9 tonnes if we take into account the processing and transportation of the fibres) for every tonne of fibre and with respect to hemp, it is about 0.4 tonnes of CO2 per tonne of hemp grown. In other words, hemp offers an 80% reduction in carbon footprint. Even when the processing and transportation to manufacture NFCs are included, the carbon footprint is still 50% lower than that of fibreglass composites (Barth & Carus, 2019). Figures 58, 59, and 60 as well as Table 6 indicate hemp's advantages in carbon uptake.

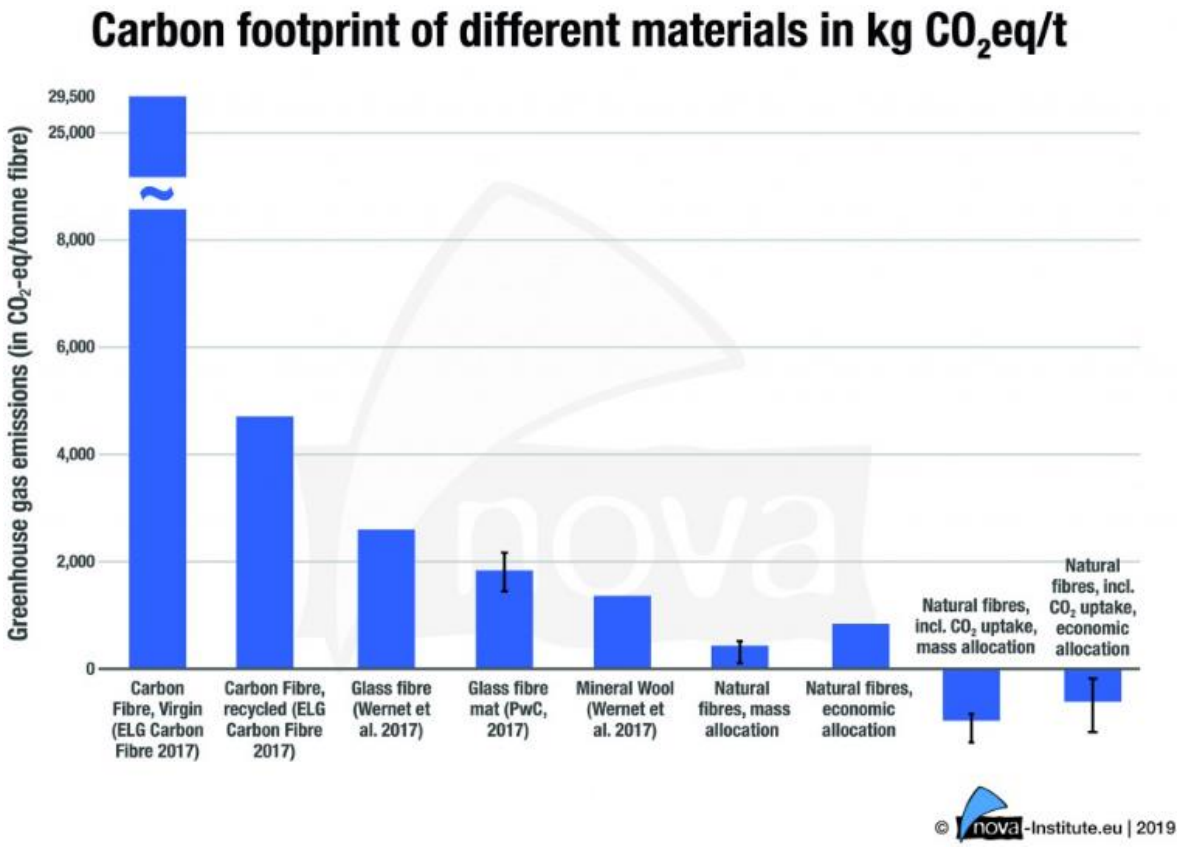


Figure 58: The Carbon footprint of various materials (Barth & Carus, 2019)

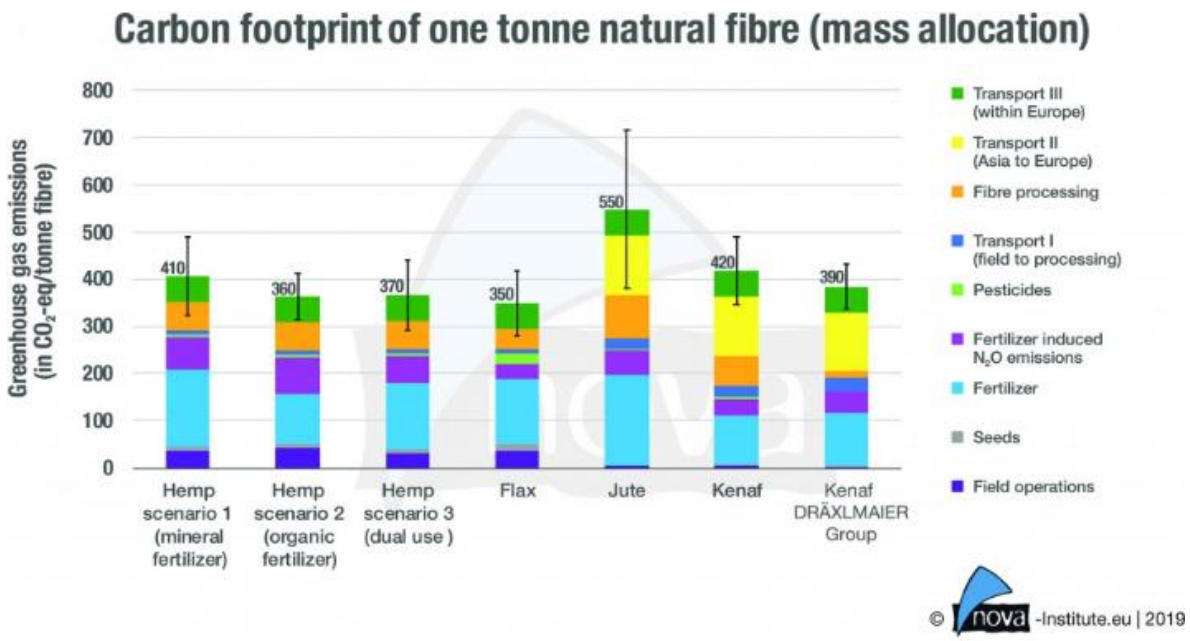


Figure 59: The Carbon footprint of Natural fibres (Barth & Carus, 2019)

Though natural fibres such as hemp have a carbon footprint, hemp is considered “carbon negative” as the crop takes up about 1.4 tonnes of carbon. Therefore, 1 tonne of CO2 is absorbed for every tonne of hemp produced. This process of absorbing carbon via photosynthesis is called biogenic carbon storage (Barth & Carus, 2019).

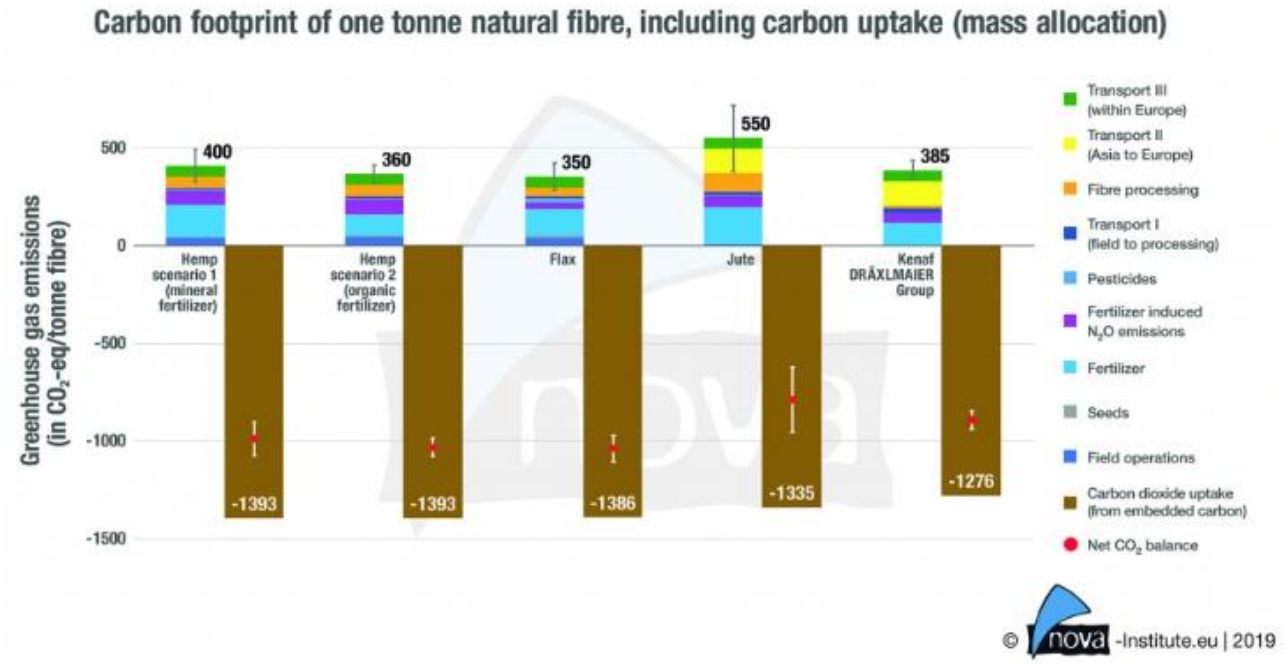


Figure 60: Carbon footprint vs carbon uptake of natural fibres (Barth & Carus, 2019)

	Unit	Flax	Hemp	Jute	Kenaf
Cellulose	kg/kg fibre	0.72	0.65	0.57	0.55
Hemicellulose	kg/kg fibre	0.18	0.15	0.13	0.14
Lignin	kg/kg fibre	0.03	0.10	0.14	0.12
Stored carbon dioxide	**kg CO_2-eg/kg fibre**	**1.39**	**1.39**	**1.33**	**1.27**

Table 6: Biogenic carbon storage in natural fibres (Barth & Carus, 2019)

Hemp fibre composites can reduce greenhouse gas emissions by up to 50% compared to petrochemical-based composites (Fig 61). This number reduces further to about 70% when considering carbon storage (Barth & Carus, 2019).

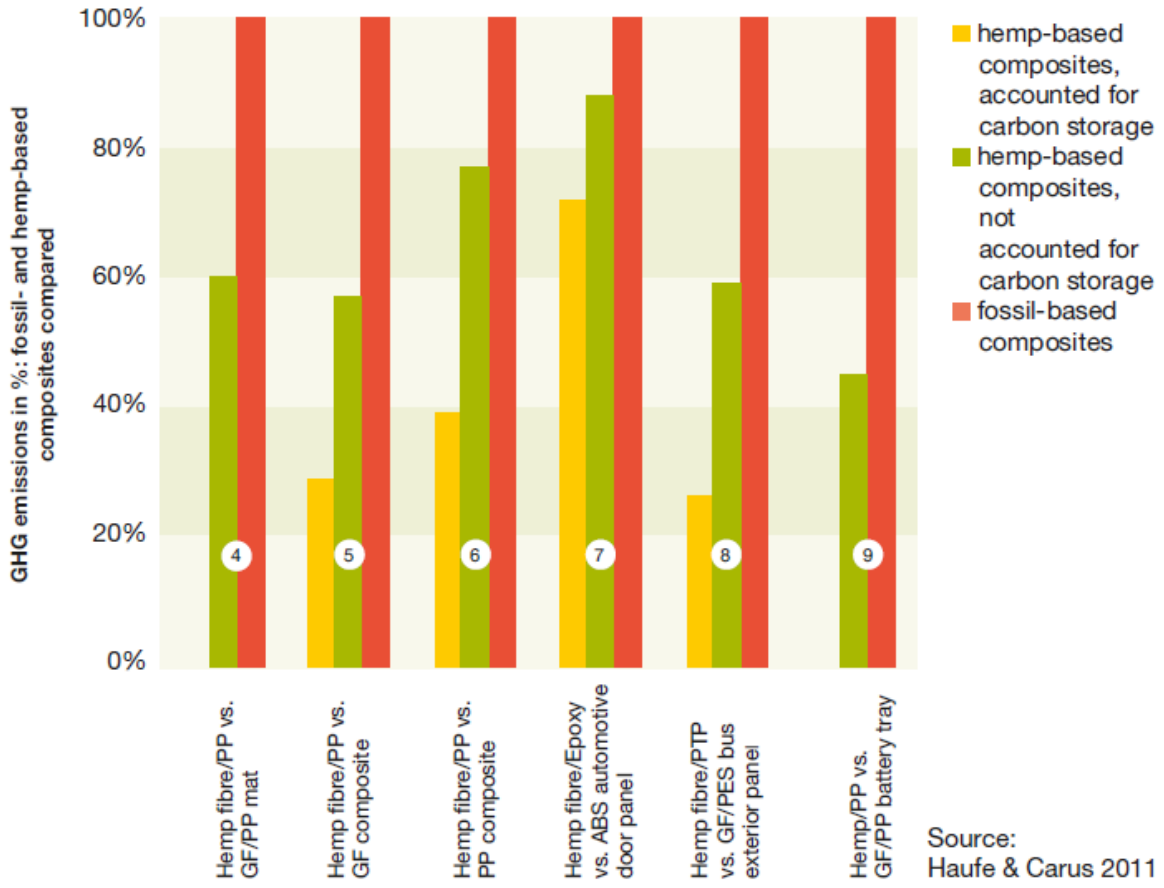


Figure 61: The greenhouse gas emissions of hemp composites vs glass fibre and other petrochemical composites (Barth & Carus, 2019)

2.5.2. Regulatory Barriers and Production Constraints of Hemp Fibre

In 2006, industrial hemp was licensed to grow legally in Aotearoa New Zealand under the Misuse of Drugs (Industrial Hemp) Regulations 2006 Act. As of 2023, the general licence fee is $511.11, which permits farming and processing of the crop (*Industrial hemp licensing NZ*, 2019). After eight decades of prohibiting this crop because of its association with marijuana, this legalisation allowed Aotearoa New Zealand to enter the industrial hemp market (Marsh, 2020).

According to Dave Jordan (CEO of Hemp NZ), lack of processing facilities was the primary constraint for a large-scale hemp fibre production in Aotearoa New Zealand. But this will change once they receive their Decorigator machine sourced from Australia (Marsh, 2020). One of the main commercialisation constraints is the production of NFCs with aligned hemp fibres, specifically for performance-driven applications (Müssig et al., 2020). In Europe, flax is currently winning the NFC market, mostly due to the previous restrictions on hemp production and the easy availability of flax, making flax the preferred material used for boat building there (Castegnaro et al., 2017).

Unlike synthetic fibres which are infinite, it is not easy to get a consistent fibre length from hemp. The twist in yarn can inhibit composite strength, and it is necessary to have more twist to manufacture stronger yarn. It is also difficult to predict the behaviour of the interlaced fabrics in the composite reinforcements (Corbin et al., 2020).

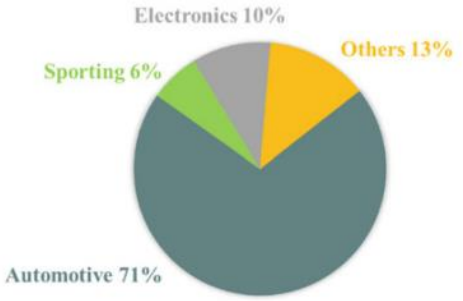
2.6. SOCIO-ECONOMIC IMPACT AND MARKET OPPORTUNITIES OF NATURAL FIBRE COMPOSITES

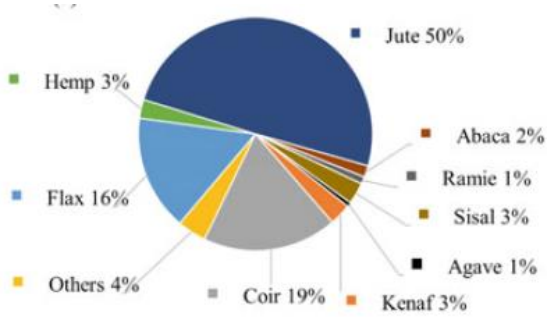
There is a high demand for sustainable products that are organic and eco-friendly, which has, in turn, increased the hemp industry's growth (Schluttenhofer & Yuan, 2017). The depletion of petroleum reserves and its destructive impact on our environment has led researchers to explore alternatives to synthetic fibre. Compared to synthetic composites, the commercial benefits of using NFCs with polymer matrices are gaining popularity due to their cheaper costs, biodegradability, and abundance (Corbin et al., 2020; Shekar &

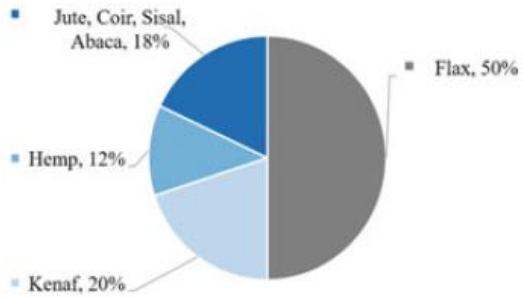
Ramachandra, 2018). Globally, there is a renewed enthusiasm for reviving the lost glory of industrial hemp through the push for legalisation with support from politicians (Fike, 2016). Legalisation is only one aspect of opportunity creation. Most new crops in agriculture usually take about 10-15 years to start a revolutionary adoption by farmers. While more business people and developers are aware of hemp's financial benefits, fewer are aware of its environmental advantages such as its benefits to carbon savings and low environmental impact compared to other materials (Small et al., 2002).

The forecast for the natural fibre market segment alone anticipates growth of 300% over the next 25 years (SSUCHY, 2020). The bio-composites market was valued at $16.4 billion in 2016 and exhibited an annual growth rate of 14.44%. By 2019, natural fibre composites (NFC) accounted for approximately 11% of the market share, representing 9% of the total value in the composites market (Placet, 2022). The hemp industry is growing globally at a 34% CAGR and will reach a targeted forecast of 64.8 billion USD by 2030. Though the current market share is dominated by CBD oil, there is high demand for Hemp fibre (Marsh, 2020). In 2019, 6.8 million tonnes of natural fibre were produced globally, and 3% of this market share belonged to hemp fibre production (Elseify et al., 2021). The demand for hemp-based products saw a threefold rise in hemp production, increasing from 16,000 hectares in 2013 to 45,000 hectares in2017 (Müssig et al., 2020). Globally, in 2018, about 50,000 hectares were used solely for cultivating hemp (Barth & Carus, 2019). Natural fibre's consumption in the global composite market is at 5%, with short thread most dominant in this segment; however, due to the high-performance applications of long fibre hemp, increasing (JEC, 2022). The marine composites market has a growing trend of adopting new materials, specifically natural fibres, and bio-resins. The push towards a greener future opens new opportunities in the boat building industry (Dokos, 2013). New opportunities are also rising with the technological advancement in nanocrystalline cellulose production, which are changing the bio-composite landscape (Faruk et al., 2012a).

NFC revenues (based on Figure 62,63, 64, and 65) were at USD 742 million in 2016, with its primary application in automobile interiors and other insulation products (Elseify et al., 2021). Hemp's global market presence has doubled from 2016 to 2020.







Figures 62,63 & 64: The revenue of USD 742 Mn from Natural fibre composite revenue based on application (top left), Vegetable fibre allocation in world production of 6.786 Million tonnes in 2019 (top right), The type of natural fibres of the total volume of 30,000 tonnes, used for reinforcements in composites in the automotive industry (bottom left) (Elseify et al., 2021)

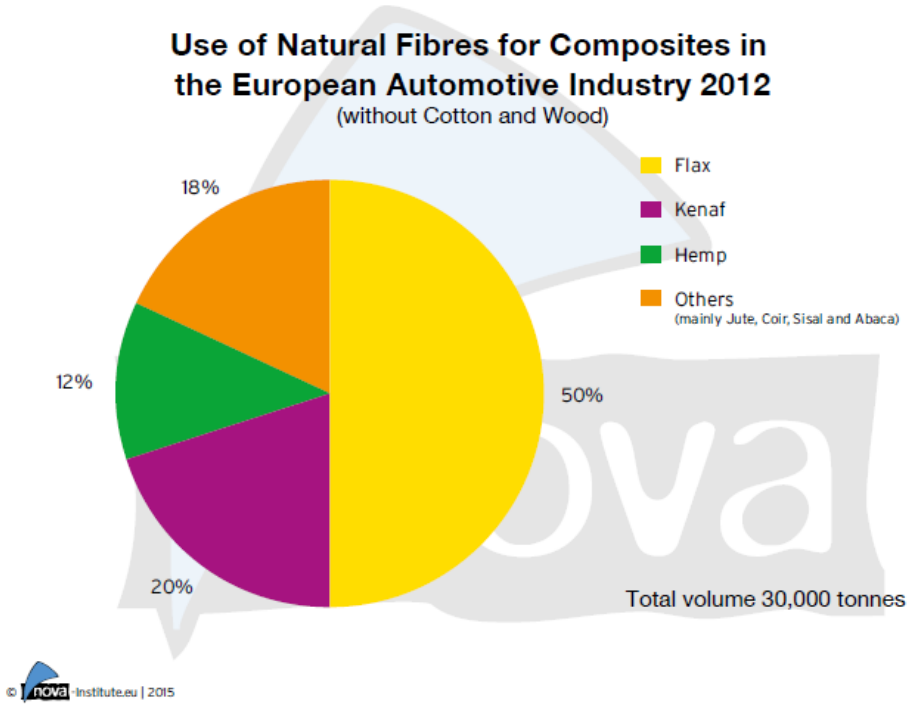


Figure 65: Natural fibre usage in composites, specifically for the European automotive industry, 2012 (Barth & Carus, 2019)

Only 3.5% of the earth's available biomass is used to generate wealth globally. 70% of this 3.5% biomass goes towards generating a wealth of USD 400 billion in revenue from food. About 2.5% of the 3.5% of biomass goes towards developing wealth and another USD 400 billion in revenue from chemicals and plastics. Hence, natural plastics and composites can

bring about a green revolution in combating the climate crisis and generate positive economic impact. The first benefactors of this change would be the farmers and SMEs (Davis, 2020).

About a quarter of the industrial hemp market share belongs to Europe (Müssig et al., 2020). Founded in 1951, one of the most significant contributors to the growth and betterment of the hemp and flax fibre value and supply chain is the CELC, the European Confederation of Flax and Hemp. About 10,000 predominantly European enterprises that contribute to fibre production and product development belong to the CELC. The hemp fibre production in 2016 was 25,000 tonnes, of which 57% was for manufacturing paper, 26% for insulation products, and 14% for bio composites. The supply and production chain for hemp fibres has drastically improved and is currently secure and stable (JEC, 2019). The European company Linificio e Canapificio Nazionale manufactures linen and hemp yarns with an annual production of 4.5 million kg of yarn and 1 million metres of fabric. With a turnover of 50 million Euros, the company forecasts that in the next 4-5 years, 10% of yarns and 15% of Fabrics will be hemp-based. For this purpose, they have invested 2.5 million Euros into their production plant in Italy (SSUCHY, 2022b)

Nathan Armstrong (Director and president of Motive Industries, Canada's first bio-composite electric car manufacturer, "Kestrel") believes they can manufacture about 100 cars per acre of hemp annually. They built their vehicles using hemp composites because of the low cost of market entry into the automotive segment. On average, an automobile manufacturer must invest USD 700 to 800 million in tooling for the vehicle's steel body panels. In comparison, NFC body panelling using hemp costs only about USD 5 million. That makes the development cost of NFC body panel cars about 160 times lower than regular steel body panel cars, lowering the end price to customers. It is also expensive to source and process steel for manufacturing purposes; when considering the environmental impacts of mining and processing steel, hemp composites seem to be a much better choice. Motive industries are now targeting product markets like bathtubs, small boats, and jet skis where traditionally chopper gun fibreglass is used; hemp composites can be an excellent replacement, being 10% cheaper to build and 20% lighter (Davis, 2020). The composites

industry is propelled by the small boat segment since bigger boats require unique materials like carbon fibre (Dokos, 2013).

Boat builder Friedrich Deimann, the creator of the Flax27 Day boat (see Figures 66 and 67), said he was optimistic that using composites with natural fibres and bio-resins will be common by the next decade. He mentions there is much talk about hemp composites but not much use in actual practice. Building with natural fibre composites costs much less than a fibreglass boat. Smaller boat builders are trying to differentiate themselves from competitors by introducing hemp composites (*Eco Boat Building*, 2021).



Figures 66 & 67: The Flax 27 Daysailer high-performance boat (Left), The bow of the daysailer, showing the weave pattern of the flax fabric used for the composite (Right) (Schmidt, 2020)

Aotearoa New Zealand's reputation as a green and nature-friendly brand can be positive for the export market (Marsh, 2020). In Aotearoa New Zealand, areas like Motueka are excellent for industrial hemp farming. Focusing on this industry can also improve the struggling local economy (Merfield, 1999). The US is the biggest target market for Aotearoa New Zealand hemp fibre manufacturers. Between 2012 and 2017, 26% of the new hemp product launches were from the US (*Global hemp markets products and consumer landscapes*, 2019).

Richard Barge, the chair of the NZ Hemp Industry Association Inc (NHIA), mentioned that the demand for fibre is the highest in the hemp farming industry (Marsh, 2020). Generally, the government promotes construction materials in the low-carbon category, creating a strong need for such products (Marsh, 2020). The Aotearoa New Zealand government is optimistic regarding the future of hemp fibre. Through the Ministry for Primary Industries (MPI) and its Sustainable Food and Fibre Futures fund (SFF Futures), it contributed $1.34 million in 2021 for a five-year research and development project undertaken by Aotearoa New Zealand

Natural Fibres (NZNF). NZNF, overseeing the complete supply chain of hemp production and processing, has invested about NZD$2 million. They are developing a diverse range of products, from soft floor boarding to food packaging (MPI, 2021). In Aotearoa New Zealand, between 2018 and 2019, the hemp licenses increased from 65 to 169. As per the NZHIA, between 2019 and 2020, about 1200 hectares were devoted to industrial hemp farming in Aotearoa New Zealand. A hectare of hemp farm can produce about three metric tonnes of fibre, retailing at NZD 2$ per kg, putting the average revenue at $500/ton (Marsh, 2020).

There are two hemp processing companies in Aotearoa New Zealand, Hemp Central and Hemp Aotearoa New Zealand. Their processing machines were purchased from the same company, Ashford Hemp Industries, New South Wales, Australia (Harris, 2023). The co-owner of the Ashford Hemp Industries, Connie Mino, is optimistic about the hemp industry's growth. Currently, their processor machines are primarily used to make hemp hurds as the demand is mainly for building hemp homes with hempcrete (Harris, 2023). In 2023, KiwiFibre Innovations Ltd, a company based in Aotearoa New Zealand, successfully secured $1.5 million in funding from Icehouse Ventures. This funding supports their ambitious project to develop industrial composites made from harakeke fibre. Harakeke, a plant indigenous to Aotearoa New Zealand, resembles flax and holds significant cultural value for Māori who traditionally used it in crafting items like mats and clothing. The company aims to bring this historically significant crop back into widespread use (Harvie, 2023). Overall, this shows the support from the Aotearoa New Zealand government and their push towards adopting natural fibre composites.

2.7. SUMMARY

It is clear from this chapter that the future of the Aotearoa New Zealand boat building industry and the global growth of NFCs (including hemp composites) are on an upward trend with positive growth for the foreseeable future. The proven strengths of hemp fibre reinforced composites compared to fibreglass composites have been validated in the automotive industry and various other sectors. However, to date little is known about the

behaviour of hemp bio-composites in marine environments, which is a crucial decision factor for its adoption by the boat building industry.

The criteria for assessing the commercial viability for New Zealand boat building to adopt hemp bio-composites, boils down to two points. The first is the technical performance of hemp bio-composites compared to fibreglass composites in extreme performance applications and marine environments. The second is the need for a strong supply chain of hemp fibre, leading to large-scale industrial hemp farming adoption.

This literature review has identified potential issues, supporting factors and a few challenges for adopting hemp bio-composites in the mainstream boat building sector. The positive outcome is the overall rise in the adoption of natural fibres in composites and the acceptance of flax-based bio-composites for performance-based applications in both the automotive and boat building industries. With the global easing of regulations on industrial hemp farming, there is a promising future for hemp bio-composites.

The challenge that persists is the lack of awareness regarding the crop's potential and its negative association with marijuana as a narcotic. The lack of knowledge also impacts farming adoption, thereby affecting the hemp fibre supply chain. Though hemp fabric and yarns are available for textile clothing applications, its fabrication for composite manufacturing is extremely low. This challenge can only be overcome through government promotions advocating for the adoption of this crop and supporting further research. With Aotearoa New Zealand's recent greenlighting of this multifaceted crop and the easing of regulatory constraints, there has been a gradual increase in its acceptance and awareness among farmers, innovators, and architects throughout the country.

CHAPTER 3: METHODOLOGY

The study seeks to explore the suitability of hemp fibre to replace glass fibre in the boating sector, which requires an exploration of the manufacturers' and builders' attitudes towards/ perspectives on each product. This approach aims at revealing the manufacturers' beliefs and biases about hemp fibre and its technical/ structural properties. Moreover, since industrial hemp is closely associated with marijuana, manufacturers may also be morally prejudiced against hemp fibre. This also needs to be considered when large-scale commercial adoption is questioned. This chapter outlines the research design, data collection, and analysis methods used to arrive at the findings of this study. As the study seeks to explore people's opinions and biases, a qualitative research design was chosen. Thus, interviews were used to develop/ gain an understanding of the different perspectives of the participants on the potential of hemp fibre reinforced composites.

3.1. QUALITATIVE RESEARCH

The research design used qualitative research methods such as interviewing boat manufacturers, composites manufacturers, farmers, and other government organisations involved in trade, marine, fibre, and farming industries. Interviewing was required to understand the social and cultural aspects of the participants' decision-making. Along with collecting qualitative data through interviews (Strauss & Corbin, 1998), intensive field observations were also made. A semi-structured format of interviewing the participants was adopted since it allows for flexible interviewing (McCombes, 2021). The interpretations of the research inputs and outputs were based on the interviewee’s perspectives of their experiences (which is the qualitative data). The qualitative data analysis was done using “thematic analysis”, as it has more to do with pattern identification and interpretation of different themes that the researcher arrives at.

The concept sample prototypes (see figures 70 to 105) developed were part of the researcher’s exploration to better understand the potential of hemp fibre in composites development and act as conversation starters with the composite boat builders or hemp

expert during the interview sessions. Various samples were produced using different combinations of hemp fibre (continuous, non-continuous, and particulate) in a resin matrix. For the matrix, PLA (Polylactic acid) 3D prints, mycelium, honeycomb cardboard and cork were explored.

This is the reverse of traditional scientific research, which takes a deductive approach which begins with a theory, developing hypotheses from that theory, and then collecting and analysing data to test those hypotheses. In this thesis project this researcher collects data (starting with an interest and collecting data via interviews) to arrive at a theory (Strauss & Corbin, 1998). In essence, the researcher followed an inductive qualitative research design. Using this, the researcher arrives at themes and concepts mapped out from the collected data. These themes were then integrated to develop a theory firmly rooted in the collected data. The flowchart in Figure 68 summarises this process.

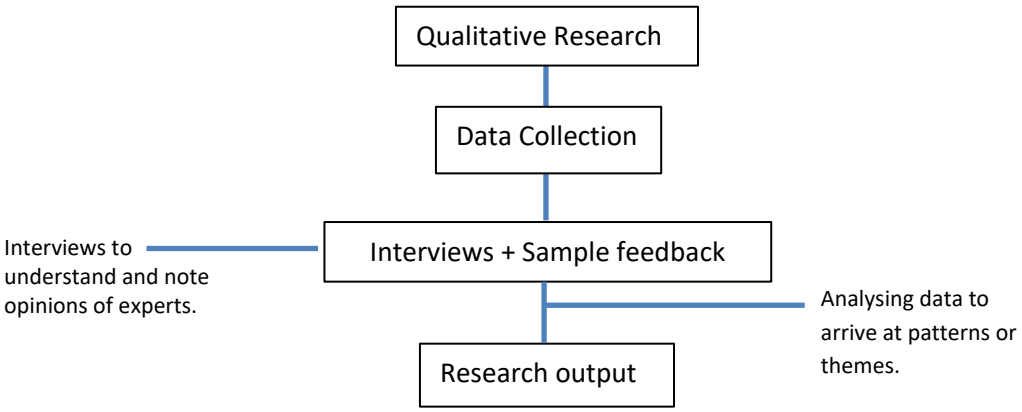


Figure 68: Qualitative research flow

When subjective and social constructions are analysed, a base is required, as the research aims to blend the participant's understandings and concepts into the findings. Qualitative analysis is highly effective for Interviews. This approach is necessary due to the individualistic differences bound to come from people during the research and the need to reflect on various ideas discussed. The relationship between the interviewees and the researcher is more participatory and interactive (Dudovskiy, 2022).

The primary data was collected from interviews with senior management or C-Suite individuals (top executive management team members). Implementing this type of

questioning and analysing tends to be applicable when the kind of information required by the researcher has more to do with understanding what a participant thinks and does with regard to a specific problem. The main advantage of this approach is that the value of the data generated from the leaders or expert professionals can be regarded as more dependable. There are disadvantages to this, too, the most common being that the data analysis focuses on the personal opinions and biases of the interviewee; hence, the data cannot be generalised (Dudovskiy, 2022).

As patterns are identified from observations, this process works by analysing certain decisions or biases and understanding why they are so (Ryan, 2018). As researchers, the question "why" is often used to find any indication of a certain phenomenon during the interview sessions (Strauss & Corbin, 1998), which further helps recognise patterns to form themes. As explained by Walsham below, the researcher needs to analyse all these data and arrive at a pattern on their own.

"I tend to use a looser approach myself, where I write impressions during the research, after each interview, for example. I generate more organized sets of themes and issues after a group of interviews or a major field visit. I then try to consider what I have learned from my field data. If this sounds a rather subjective and relatively unplanned process, well it is. I believe that the researcher's best tool for analysis is his or her own mind, supplemented by the minds of others when work and ideas are exposed to them." (Walsham, 2006, p. 325)

3.2. DATA COLLECTION METHODS

The study is based on two types of data, namely interviews and feedback on hemp fibre samples developed by the researcher.

Scouting for boat builders to recruit for interviews took place at two events: The Auckland Boat Show 2023 (see Figures 119 to 121) and the Hutchwilco Boat Show 2023, Auckland. One of the exhibitors at these shows, Offshore Cruising Tenders (OCT), agreed to an in-person meeting. It subsequently led to the joint prototype development of a boat component using hemp-reinforced composite material to understand its potential. While most boat builders were initially open to being interviewed for the research, some did not

respond upon follow-up. Out of the 15 boat builders contacted, only six ultimately agreed to be interviewed.

The iHemp Summit 2023 in Christchurch allowed the researcher to display material samples and initiate conversations with hemp industry experts, farmers, and entrepreneurs. The researcher also presented at the event as one of the speakers and participated in a panel discussion. This led to more in-depth discussions and personal interactions post-panel concerning the material samples. The summit served as a platform for recruiting several hemp experts and entrepreneurs from the hemp industry. Out of the 35 hemp experts contacted, only 14 agreed to be interviewed.

In preparation for the interviews, it was essential for the researcher to obtain ethics clearance approval from AUT (see Appendix B). To ensure the ethical conduct of the study, a consent form was distributed to all interviewees. This form clearly stated the commitment to confidentiality, guaranteeing that the identities of the participants would remain undisclosed under any circumstances.

Interviewing is one of the most common data collection methods in qualitative research, the most used format being semi-structured interviews. This type of interview format uses open-ended questions, which is suitable for research studies where in-depth interviews and deeper insights are required (Jamshed, 2014).

Each interview began with the researcher introducing the topic and the importance of the interviewee's opinions for the success of this research. During the initial discussion, samples of hemp bio-composites were displayed as a conversation starter. This particularly helped generate interest among experts unaware that hemp bio-composites existed. On average, an hour of semi-structured interview would take about 5 to 6 hours to transcribe, and the analysis would take about 4 hours. That meant that the researcher spent approximately 10 to 11 hours per interview, which includes the recording, transcription, analysis, and documentation. Unlike quantitative analysis, qualitative analysis can begin right away. This ultimately helped with gaining early insights, which in turn helped the researcher fine-tune the questions in subsequent interviews. (*Tips for Qualitative Analysis*, 2023).

The interview questions consisted of a core question and several subsets of questions. Interviews were recorded in a written, audio or video recording format, comfortable to the interviewee. Note-taking via writing was least preferred by the interviewer, as it breaks the flow of questioning and tends to be the most unreliable. However, it was used if a participant refused audio or video recording. In general, an audio or video recording helped the interviewer stick to the questionnaire and the interview content and remain attentive to the verbal cues of the interviewee (Jamshed, 2014). The non-verbal cues were also observed during the interview session. These cues included laughter, silence, and others, providing insights that can be recorded only by observation (Kakilla, 2021).

The recruitment strategy used to gather participants was through direct and indirect contact. The researcher approached several boat builders and marine composite manufacturers at boat shows, particularly the Auckland boat show and the Hutchwilco boat show in 2023. This helped with generating a list of potential experts from the boat building industry. Each expert was approached via emails and phone calls, inviting them to participate in an interview on the commercial viability of hemp bio-composites for boat building. As a guest speaker and exhibitor, the researcher attended the iHemp Summit 2023, Christchurch, Aotearoa New Zealand. Attending the summit helped the researcher to network and connect with participants from the hemp industry in Aotearoa New Zealand and Australia. The purpose of gathering insights from hemp industry experts was to understand the supply chain of hemp as a fibre and its adoption by farmers.

The interview data and sample feedback analysis generated codes and themes for both participant groups, namely the boat builders (including composite experts) and the hemp experts (including industry experts, retailers, wholesalers, entrepreneurs, and startups). This led to common themes pertaining to both participant groups.

3.2.1. Interviews

The most crucial part of this qualitative research were the interviews. They were the key data that informed the point of views of the experts within the industry domain that are presented in this thesis. The interview audience was split into two categories: the boat

builders and marine composite manufacturers working with fibreglass and the second being hemp manufacturers, experts, and farmers. At the beginning of each interview the researcher asked the interviewee to introduce themselves and explain their field of expertise. Then, the researcher asked questions to determine the interviewee's fundamental knowledge of NFCs. This was followed up with a display of the samples made by the researcher. This sample display was mostly used as an icebreaker and casual conversation starter. It was hoped that, when interacting with the samples, the tactile (touch and feel) factor would pique the interviewee's interest and lead into the next interview stage, which focuses primarily on the commercialisation aspects of the material.

Schedule for interviews with boat builder

Section 1: Self Introduction by Participant

1. Could you please introduce yourself and explain what you do?
2. How long have you worked in the industry?
3. Please provide a brief history of your company.

Section 2: Awareness and Perception of Hemp Bio-Composites

1. How familiar are you with hemp bio-composites and their potential applications in the boat building industry?
    a. Very familiar b. Somewhat familiar c. Not familiar d. I never heard of it e. Prefer not to answer
2. Are you aware of any successful case studies or examples of hemp bio-composites used in boat building or other industries? If yes, please provide details.
3. What are the main advantages of using hemp bio-composites in boat construction compared to traditional materials like fibreglass composites?
4. Have you come across hybrid glass and NFCs?

Section 3: Commercial Viability and Sustainability

1. Can you share the annual revenue from composite product sales if you wouldn't mind? And what current innovations are you planning to implement in the coming models?

    a. Prefer not to answer.
2. How much fibreglass does your company consume per year, and how much does a square meter of material cost you on average for boat production?
    a. Prefer not to answer
3. Do you believe hemp bio-composites have the potential to be commercialised within the boat building industry? Please explain your reasoning.
4. What factors do you think will contribute to the success or failure of hemp bio-composites as a viable alternative to fibreglass composites in boat construction?

Section 4: Regulatory Barriers and Production Constraints

1. What are your industry's current regulatory barriers or production constraints, such as pollution control, waste disposal, or material sourcing?
2. Are you aware of any regulatory barriers or production constraints related to using hemp bio-composites in boat building? Please provide details.
3. In your opinion, what are the best strategies to address these regulatory barriers and production constraints?

Section 6: Current FRP construction

1. Could you explain more about the types of boats/ products you manufacture using FRP composites?
2. Please explain your boat's construction process.
3. How many types and layers of fibreglass mats are used to construct the hull?
4. What is the preferred thickness and GSM per square metre or square inch?
5. Have you tried bio-epoxy?
6. Do you use PET foam between your top and bottom FRP layers? What do you think is the best thickness required for strength and insulation? How do you measure it?

Section 5: Opinions on samples and adoption of hemp fibre

1. Given the provided hemp bio-composite samples, please share your opinion and understanding about the suitability of these hemp bio-composite samples for boat building.

2. In your opinion, what might be the best option to improve this material sample?
3. What tests would you recommend as a boat builder/ composites manufacturer to evaluate the potential of these samples for replacing fibreglass composites?
4. As a stakeholder in the boat building/composites/ Industrial hemp industry, what are your main concerns or reservations about adopting hemp bio-composites in your operations?
5. What factors would encourage or discourage your organisation from adopting hemp bio-composites in boat construction?
6. If hemp composites were to perform at par with fibreglass composites, at what price would you be encouraged to shift to hemp bio-composites?

Section 6: Future Opportunities and Challenges

1. What is your plan and vision for your company as part of the composites/boat building industry in Aotearoa New Zealand?
2. Do you see further research and development opportunities in hemp bio-composites for boat building?
3. What challenges will the industry face in terms of the transition from traditional materials like fibreglass composites to more sustainable options like hemp bio-composites?
4. Are there any other comments or insights you want to share regarding hemp bio-composites and their potential in the Aotearoa New Zealand boat building industry?

Thank you for your participation in this interview. Your input is invaluable in contributing to the development of sustainable practices in the boat building/ composites sector and the growth of the local hemp industry in Aotearoa New Zealand.

Schedule for interviews with Hemp experts

Section 1: Self Introduction by Participant

1. Could you please introduce yourself and explain what you do?
2. How long have you worked in the industry?

3. Please provide a brief history of your company.

Section 2: Awareness and Perception of Hemp Bio-Composites

1. How familiar are you with hemp bio-composites and their potential applications in boat building or other industries?
    a. Very familiar b. Somewhat familiar c. Not familiar d. I have never heard of it e. Prefer not to answer
2. Are you aware of any successful case studies or examples of hemp bio-composites used in boat building or other industries? If yes, please provide details.
3. What are the main advantages of using hemp bio-composites to traditional materials like fibreglass composites?
4. Have you come across hybrid glass and NFCs?

3.2.2. Interview Procedure

A total of 20 interviews were split into two types:

1) Boat builders and composite experts: 6 participants
2) Hemp experts/ farmers/ retailers/ and wholesalers: 14 participants

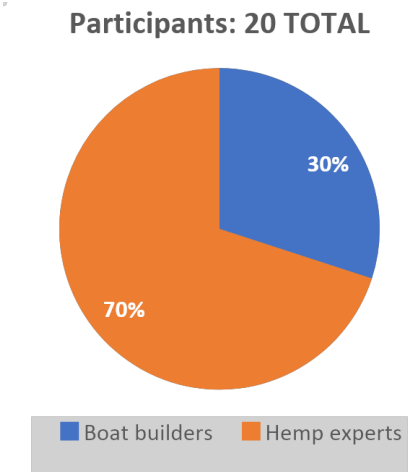


Figure 106: Total participant representation

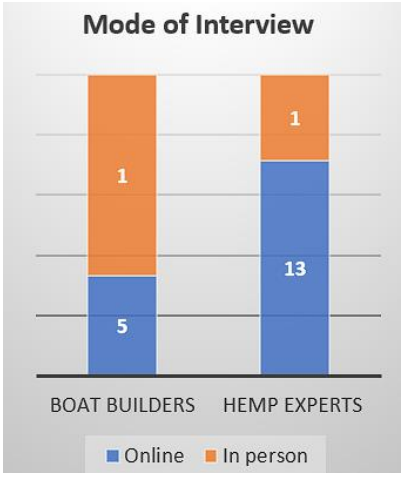


Figure 107: Participant Interview Mode Representation

When first approached, nearly 50 participants agreed to be interviewed. However, when contact was re-established for scheduling the interviews, participation dropped by at least

60%, and only 20 remained (see Figure 106). Most participants who did not participate were non-responsive, and three declined due to time constraints. A drop in the number of participants, as observed in this study, is not unusual and can be attributed to attrition. This attrition was not a significant issue for the research because the objective was to seek insights and understanding rather than to produce statistical industry data. The focus was on gaining a deeper understanding and generating solutions for the industry, making the qualitative depth of data more critical than its quantitative breadth.
The response rate in this study was lower than anticipated, which could potentially raise concerns regarding the statistical validity of the findings, especially when considered as a percentage of the total population of boat builders or hemp growers in New Zealand. This limitation is acknowledged as it can affect the generalisation of the conclusions. However, despite the smaller sample size, the data collected provide valuable insights, contributing significantly to the analysis of an issue previously unexplored in New Zealand.

When setting up a time for the interview, participants were asked if they preferred to be interviewed either online via Google Meet / Zoom or have an in-person meeting at a location of their choice. 18 participants preferred an online meeting, while the rest preferred an in-person interview session (see Figure 107). The preference for recording the interviews was also decided beforehand. Only two participants agreed to be voice-recorded; the rest preferred not to and notes were taken instead.

The interviews had the following phases:

1) Introduction: Beginning with a self-introduction by the researcher and explaining a brief overview of the research and its objectives.
2) Casual discussion and warm-up: A few minutes discussing general topics to bring the participant into a more comfortable zone.
3) Core research questions: Start with core research questions and adapt with further refined questions based on the previous responses.
4) Sample feedback: Displaying the samples of hemp bio-composites to garner an initial reaction from the participants, which further leads to questions on their part.

5) Semi-formal discussions: After the visual or tactile feedback of the samples, the participants are asked about their concerns and interests.
6) Wrapping up the interview: The researcher thanks the participants and invites them to reach out if they are interested in the material and partnerships for development.

3.2.3. Material Sourcing

Material samples were sourced from France, India, Australia, and South Africa (see Figure 69). It was challenging to source hemp fabric, both woven and non-woven, in Aotearoa New Zealand. The initial plan was to develop a material using hemp fibre sourced from Aotearoa New Zealand farms, and this remained a challenge due to its unavailability as a yarn. Hence, the decision was to focus on sourcing most materials from outside Aotearoa New Zealand.

Material Sourcing:

Woven fabrics: India, Australia, France

Non-Woven fabrics: France

Hemp 3D printing filament: South Africa

Bio epoxy resin: Hamilton, Aotearoa New Zealand



Figure 69: Materials purchased – from hemp woven and non-woven fabrics to hemp 3d printing filament, photographed by Gautam MN.

3.2.4. Sample Development and Feedback



Figure 70: Testing hemp and fibreglass Samples on Styrofoam with epoxy resin.



Figure 71: Setting up bio-resins and hemp sample swatches for composite development



Figure 72: Acrylic panel open mould with the gloss side facing up



Figure 73: Wetting open mould with Bio resins



Figure 74: Placing first hemp woven fabric of 340 gsm



Figure 75: saturating it with more bio-resin



Figure 76: Repeating the process of layering with hemp fabric



Figure 77: Applying bio resin while also removing excess resin by dabbing with a brush



Figure 78: Applying final Hemp fabric layer and saturating with Bio resin



Figure 79: Placing the 2nd acrylic panel with gloss side down to ensure gloss finish on both sides of the composite panel output

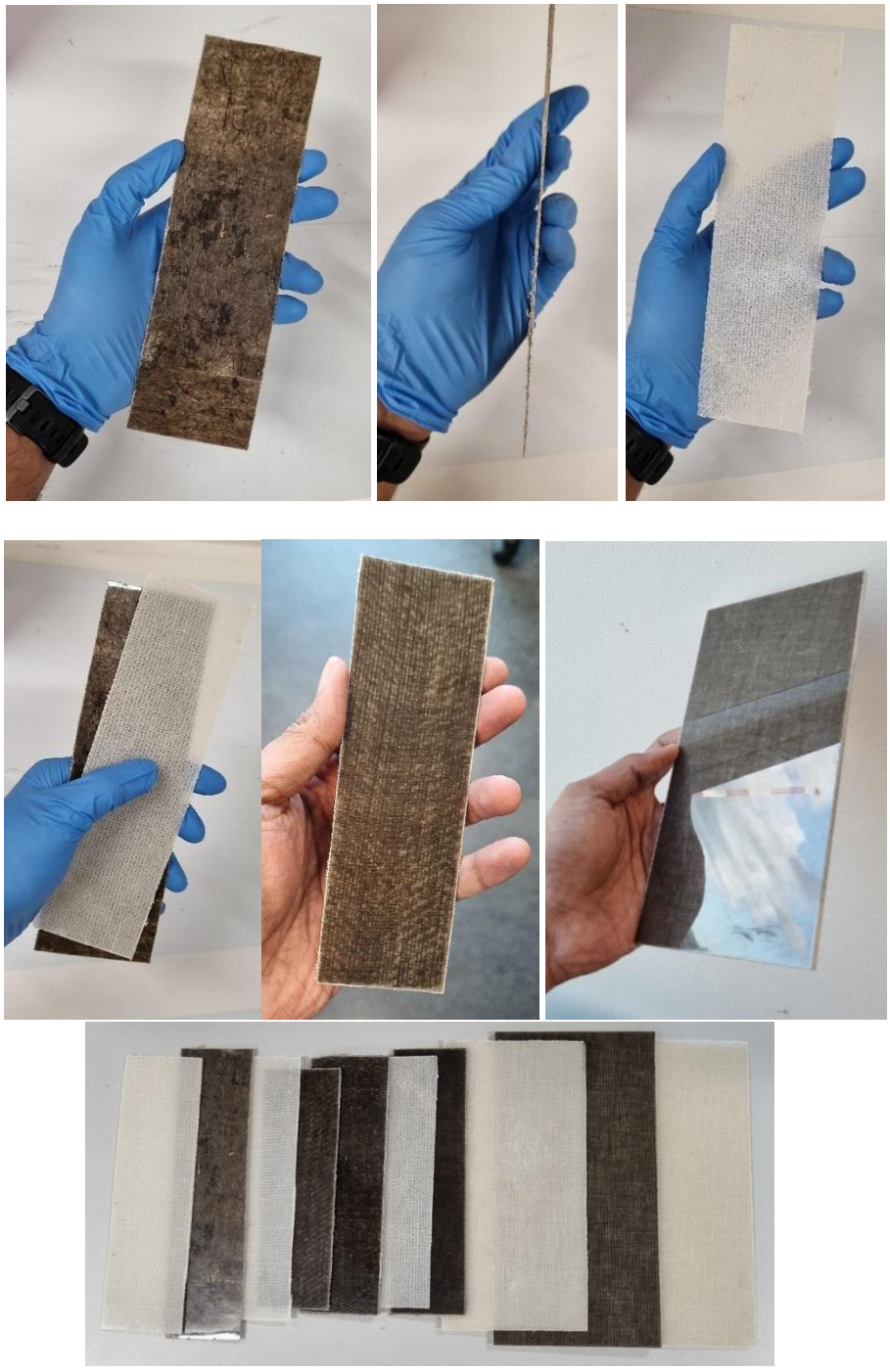


Figure 80: Placing 15kg concrete weights to compress the moulds and remove excess resins from the sides



Figure 81: The final laminate output after removal from moulds

3.2.5. Sample prototype concepts



Figures 82,83,84,85,86,87 and 88: Samples of woven and non-woven laminates were made by hand using the lay transfer method using acrylic panel moulds.



Figures 89,90,91,92,93, and 94: Mycelium composite (supplied by Biofab, Aotearoa New Zealand) laminated with hemp fabric reinforced composite, using woven and non-woven hemp fabric with bio resin



Figure 95: Hemp PLA 3d printed at AUT Creative Technologies Lab by Senior Technician Lucky Umang Singh and Technician Simon Heath

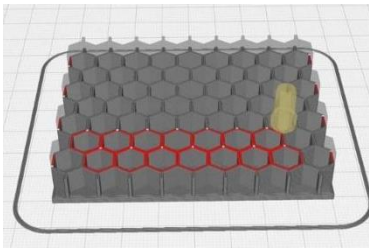


Figure 96: Honeycomb hemp PLA panel designed in SolidWorks



Figure 97: 3d printing by Senior technician Lucky Umang Singh at AUT Creative Technologies Lab

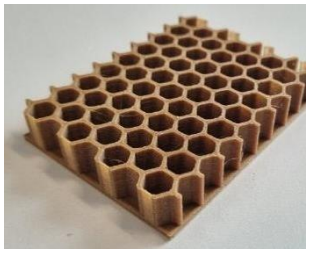
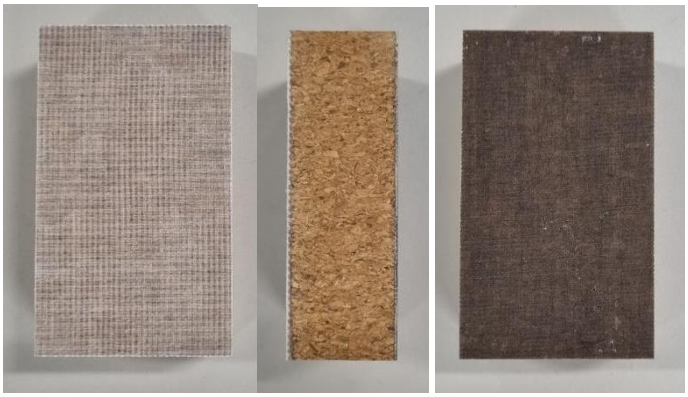


Figure 98: Final 3d printed honeycomb hemp PLA panel

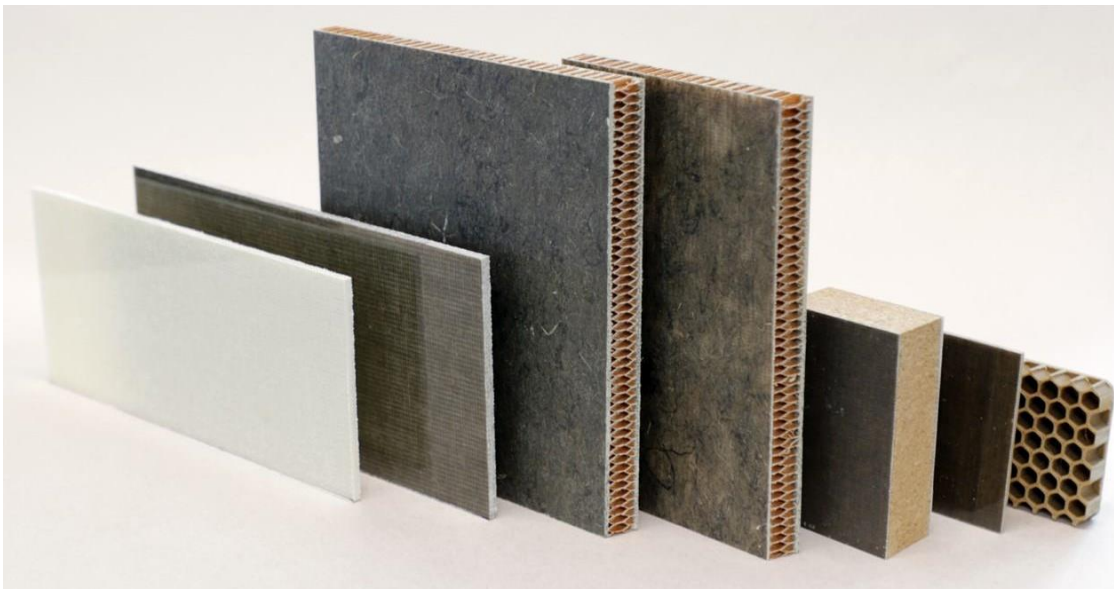


Figures 99,100, and 101: Hemp sandwich composites developed with hemp woven fabric reinforced laminates and cork as a sandwich core



Figures 102 and 103: Hemp sandwich composites developed with hemp non-woven fabric laminates and Nomex (honeycomb cardboard) as a sandwich core.



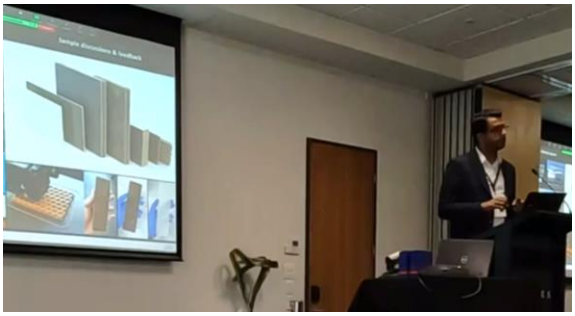


Figures 104 & 105: Final sample displays

3.2.6. Sample Feedback

Feedback on samples developed by the researcher was collected from both participant groups. The samples developed by the researcher were displayed at the iHemp summit, held on 24-25th August 2023 in Christchurch (see Figures 108 to111). This summit was attended by hemp experts, farmers, retailers, wholesalers, entrepreneurs, and startups from the US, Australia, and Aotearoa New Zealand. The CEO of iHemp Summit, Richard Barge, provided the researcher with an exhibition spot to display the samples and an opportunity to present the ongoing research as one of the speakers at the event. This led to

genuine interest from the hemp industry members and experts at the event and helped recruit participants. New Zealand companies such as RUBISCO (see Figures 112 to 117) also displayed their products at the summit. They have invested heavily in the hemp product segments and are also manufacturing non-woven hemp wool for erosion and sediment control as well as weed suppression. The company is evaluating hemp-based bio-composites and its future in Aotearoa New Zealand.






Figures 108,109, 110, and 111: The researcher presented the ongoing research at the summit and displayed samples developed, along with a poster detailing contact details for interviews and partnerships.





Figures 112 and 113: Hemp products displayed at the exhibition by various entrepreneurs and businesses.





Figure 114,115,116, and 117: Display by Aotearoa New Zealand natural fibres (NZNF) and RUBISCO



Figure 118: Conclusion of iHemp Summit by CEO and NZHIA chairman, Richard Barge



Figure 119, 120, and 121: The Auckland boat show held on March 23-26,2023, at Auckland, Aotearoa New Zealand

In addition to creating sample prototypes, a comparative cost analysis was conducted to evaluate the expenses involved in producing these samples relative to their fiberglass equivalents. This analysis was aimed at assessing the practicality and economic viability of adopting this new material. The cost was determined by comparing the prices of Fibreglass fabric and resins available in New Zealand, using popular NZ websites, against the prices of imported hemp fibre fabric and Bio resin.

3.2.7. Hemp-Reinforced Bio-Composite: Joint Development with Boat Builder

A joint product development opportunity emerged in an initial interview with a boat builder recruited from the Auckland Boat Show. The collaboration was with Offshore Cruising Tenders (see Figure 122), a boat building company located in Paihia, Aotearoa New Zealand, founded by Russell (see Figure 123) and Karin Carlyon (see Figure 124). The CEO, Russell Carlyon, agreed to create a hatch lid for their 4-meter carbon fibre composite tenders using hemp-reinforced composites as an alternative material to the currently used carbon fibre (Fig 125 -157).



Figure 122: Offshore cruising tenders, boat building factory space, located at Paihia, Aotearoa New Zealand



Figure 123: The CEO, Russell Carlyon, with his children on one of his boats (OCtenders, 2023)



Figure 124: OC tenders business partner Karin Carlyon demonstrating the lightness of their carbon fibre boats by single-handedly towing it (OCtenders, 2023)

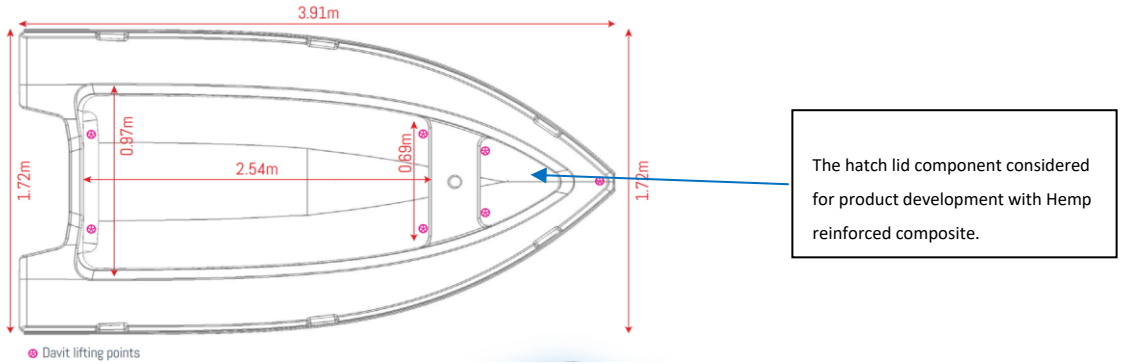


Figure 125: Line drawing for OC tender's 4-meter carbon fibre composite boat (OCtenders, 2023)



Figure 126: Final prototype of the boat hatch lid, made from hemp fibre reinforced PVC foam core composite



Figure 127: Final prototype displayed by the CEO Russell Carlyon (left), AUT Researcher Gautam M N (centre) and Senior Composite Technician Matt Loveridge (right), covered by Boating Aotearoa New Zealand magazine issue Nov 2023, pg. 21

Product Development Process with Boat builder @OC Tenders:





Figures 128 and 129: Sr. Composite Technician, cutting the hemp fabrics to size with the help of a template



Figure 130: Fibreglass mould with white gel coat preparation



Figure 131: Laying down the fabric pieces on the mould



Figure 132: Peel ply fabric (rayon) is used for easy release and to spread resin evenly during vacuum infusion. It also helps to protect the component during demoulding

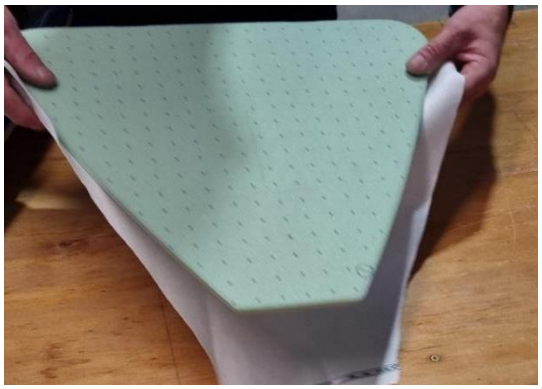


Figure 133: A PVC core encased within the fabric acting as a core for the sandwich composite





Figures 134 and 135: Assembling the fabric layers and the PVC core in the mould





Figures 136 and 137: Taping the sides of the fabric and adding the breather cloth to begin the bagging process for vacuum infusion. The breather fabric helps remove excess resin and facilitates the vacuuming within the laminate




Figures 138 and 139: Adding a bagging tube and vacuum bag to allow the resin to flow into the component



Figure 140: Preparing the resin mixture of 2 part resin and 1 part hardener



Figure 141: Creating vacuum and resin infusion




Figures 142 and 143: Post infusion while maintaining a temperature of 35 to 40 degrees Celsius in a foam chamber and a small 800 W heater for the purposes of curing the component



Figure 144: Close-up images of the component before mould release



Figure 145: Close-up images of the component before mould release

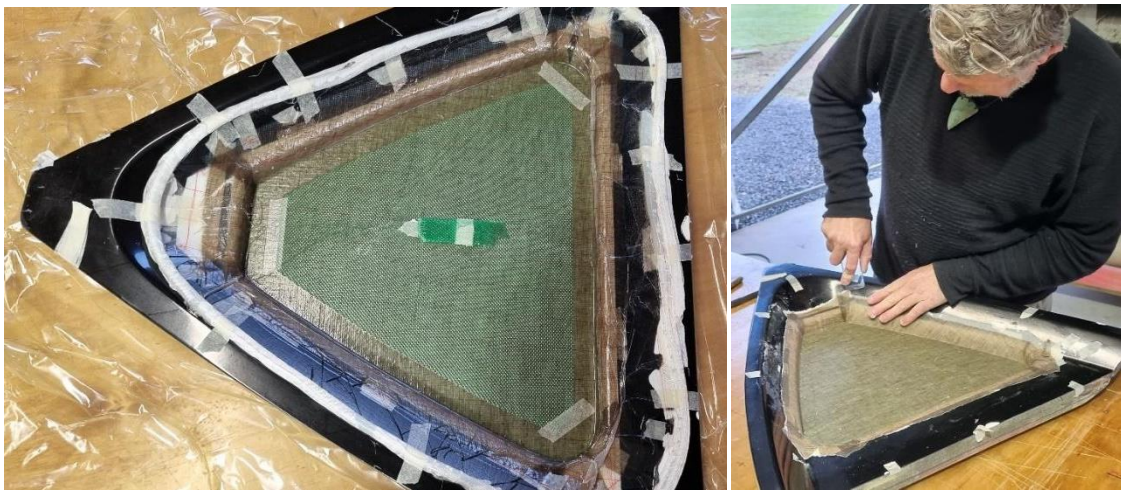
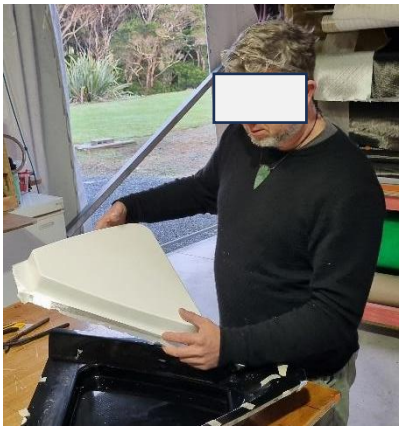


Figure 146: Removing the composite cast from the mould




Figures 147 and 148: Inspecting gel coat finish after release from mould




Figures 149 and 150: Inspection, grinding, and sanding for final finishing




Figures 151 and 152: Final inspection and manual bending test



Figure 153: Creating a lip edge to mimic the seating on the boat lid opening



Figure 154: Testing with full adult weight on the component to test flexing



Figure 155: Total weight in grams of carbon fibre composite (left vs the hemp fibre composite (right)




Figures 156 and 157: Top and bottom side finish of the final hemp reinforced PVC core composite sandwich component

The hemp bio-composite hatch lid, developed at Offshore Cruising Tenders by their Senior Technician, received high praise from both the development team and the CEO. One factory worker, who is allergic to fibreglass and therefore must wear a full-body disposable suit while working on the boats, mentioned the potential benefit of not having the allergic issue if they were to switch from fibreglass to hemp fibre mats. This suggestion was met with agreement from other team members as well. The CEO also expressed interest in extending hemp composites to other boat components or the deck, with plans to explore these options next year. Overall, the feedback was overwhelmingly positive.

3.3. SUMMARY

The methodology of this thesis, encompassing inductive qualitative research through interviews and sample feedback, is directly aligned with the investigative nature highlighted in the literature review. This approach addresses the need for a deeper understanding of industry perceptions and practical assessments of hemp bio-composites in Aotearoa New Zealand's boat building sector. The literature review points to the industry's innovative spirit and environmental consciousness (as discussed in Section 2.1.2, 'Current State of the Industry and Use of Fibre Reinforced Composites').

Furthermore, the literature review's emphasis on the ecological benefits and technical properties of hemp (see Section 2.4, 'Understanding Natural Fibre Composites' above) is substantiated through this data collection, which gathers practical feedback on hemp bio-

composites' performance and market potential. The creation of samples with the boat builders of OCT tenders further provided detailed practical feedback on the performance of the hemp composite. This integrative approach ensures that the findings are built on existing data and contribute novel insights, giving way to future research and industry-specific recommendations.

CHAPTER 4: FINDINGS AND DISCUSSION

4.1. DATA ANALYSIS

The analysis of the data collected over a four-month period was completed in approximately two months. This process included a comprehensive examination of interviews, sample feedback, and pricing information. Notably, a significant portion of the interview analysis occurred concurrently with the interview phase itself. This approach was instrumental in ensuring ample time for reflection and the development of pertinent themes. Specifically, the thematic analysis involved. This methodological approach facilitated the identification of final key codes and themes. These elements were crucial in shaping the direction of the study's conclusions and informing areas for future research.

4.1.1. Thematic Analysis Approach

The different perspectives and experiences of the two participant groups were explored using thematic analysis. Thematic analysis helped create a framework for coding and categorising the data based on the common themes in the research.

Approach:

1) **Coding:** Individual dialogues in the interviews were first tagged with codes, identifying certain information that each line provided (e.g., "Performance," "Cost Concerns," "Product Inquiry", "Existing Experience, etc.).
2) **Grouping Codes into Themes:** These codes were then grouped under larger themes that captured the broader topics discussed in the interview (e.g., "Technical feasibility," "Market Interest," etc.).
3) **Interpretation:** Finally, each theme was evaluated to determine what it reveals about the experts' understanding, attitudes, or interests regarding hemp bio-composites in boat building and other sectors.

4.1.2. Examples of code and theme development for participant groups

Sample Interview Snippet 1: With Boat Builder

Researcher:	Boat builder:
"Are you aware of hemp bio-composites or other natural fibres used in boat building?"	"Not much, but I've heard of flax being used."
"Hemp fibres can be an alternative to fibreglass in composite boat building. What is your take on that?"	"Hemp!! So, if I make a boat with hemp fibre bio-composites and if it were to catch fire, will I get high?"
"No, no, It's industrial hemp, not marijuana. You can't get high from it."	"Oh, ok. But how is its performance in comparison to fibreglass?"
"It's good and has a high specific bending stiffness, compared to fibreglass composites, but not as high as carbon fibre composites."	"Hmm... I don't know. Are any boats out there made from this material?"
"Yes, I also have some sample panels for your feedback. I developed these hemp composite panels with bio-resin at the university."	"Hmm... Interesting, that's a nice finish. I like it. But performance-wise, I'm not sure. We'll have to test it. Do you have a spec sheet? And what is this bio-resin made of ?"
"I can share some research papers with you on the tech specs. The bio resin is a USDA-approved resin made from 30% bio component; the rest is epoxy. It can easily replace your current epoxy without any issues." "How about we make a sample of one of your components to test it out?"	"Yeah, we can try. But how much do these hemp fibre and bio-resin costs compare to the fibreglass and marine epoxy resins?"
"I can bring the material for testing it out at your factory. Hemp fibre is cheaper than fibreglass, but the import cost to Aotearoa New Zealand makes it a fair bit expensive when ordered in small batches. This can be much less when ordered in bulk. And the bio-resin is at least 1.5 times more expensive than the Marine epoxy resins that boat builders use."	"That's expensive. But maybe there is a possibility for creating some components of the boat, perhaps a non-load bearing component in the boat. It has value in branding for eco-friendly boats. However, it will be difficult to adopt unless the price drops to at least at par with fibreglass composites. But yeah, some customers might be willing to pay for an eco-friendly version of the boat. We could try something out."

Table 7: Snippet of the discussion between the researcher and a boat builder

It is important to note here that the researcher ensured that the questions led to discussions on opinions based on the answers from previous questions. This led to a more

comfortable and casual discussion. The interview questions (see 3.4.2) were used as pointers to ensure none of the questions were missed. The data presented in Table 7 was collected during an initial interview and discussion with a boat builder. The connection was established at the Auckland Boat Show. Following the receipt of ethics approval, the researcher obtained permission from the boat builder to meet with again at his factory and record the interview. The initial casual conversations evolved into a more detailed interview, providing deeper insights into the boat builder's perspective on the subject. Most of the questions related to company revenue, cost of materials and core technical details were not answered in detail, and the researcher did not push for answers, as the participants' hesitancy was noticed. However, as shown in the above interview snippet, a couple of questions, such as cost economics, application constraints, and others came from the interviewees themselves later on during deep dive discussions, leading to a deeper understanding of both their preconceptions about hemp and the types of practical concerns they have with regard to switching to hemp fibre.

The following codes and themes were generated from the interview snippet presented in Table 7 above.

Codes:

1) **Material Alternatives:** In reference to flax and hemp as alternatives.
2) **Misconception:** Biases about getting high (hallucinations due to psychoactive compound consumption) from hemp.
3) **Performance:** Questions and discussions about how hemp compares to fibreglass.
4) **Cost**: Mention of material and import costs.
5) **Testing:** Experiment with new materials and the willingness to try building a sample component.
6) **Eco-Friendliness:** Understanding the value in branding for eco-friendly boats.
7) **Market Adoption:** Concerns about price and customer's willingness to pay.

Themes:

1) **Awareness:** This theme covers the "Material Alternatives" code, as it delves into new materials for boat building.

2) **Economic Feasibility:** This theme covers "Cost" and "Market Adoption" and relates to the economic implications of using hemp bio-composites.
3) **Public Perception:** This theme covers "Misconception" and those parts of "Market Adoption" that represent how public understanding (or misunderstanding) can impact the adoption of a new material.
4) **Technical Feasibility:** This theme covers the “testing” and “performance” codes and is concerned with the strength of the product and application constraints for material adoption.
5) **Green Branding & Sustainability:** This theme covers those parts of the "Eco-Friendliness" and the "Market Adoption" codes that focus on eco-friendly branding; the theme points towards a growing interest in sustainability in the boat building industry.

Example Analysis Table:

Key Statements	Code	Theme
"Not much, but I've heard of flax being used in composites."	Material Alternatives	Awareness
"If it were to catch fire, will I get high?"	Misconception	Public perception
"How is its performance in comparison to fibreglass composites?"	Performance	Technical Feasibility
"How much does the hemp fibre and bio-resin cost?"	Cost	Economic Feasibility
"we'll have to test it."	Testing	Technical Feasibility
"Perhaps a non-load bearing component, like a hatch lid."	Testing	Technical Feasibility
"There is some value in terms of branding for eco-friendly boats."	Eco-Friendliness	Green branding & sustainability
"Unless the price drops to at least at par with fibreglass	Market Adoption	Economic Feasibility

composites, it would be difficult to adopt”.		
"Some customers might be willing to pay for an eco-friendlier version of the boat."	Market Adoption	Green branding & sustainability

Table 8: Analysis of the conversation as pointers to build codes and themes

4.2. FINAL CODES AND THEMES

Based on the above examples and thematic analysis, a final set of codes and themes based on the interviews from both groups were derived.

Final Code and Theme generation for 6 Boat builder interviews and sample feedback:

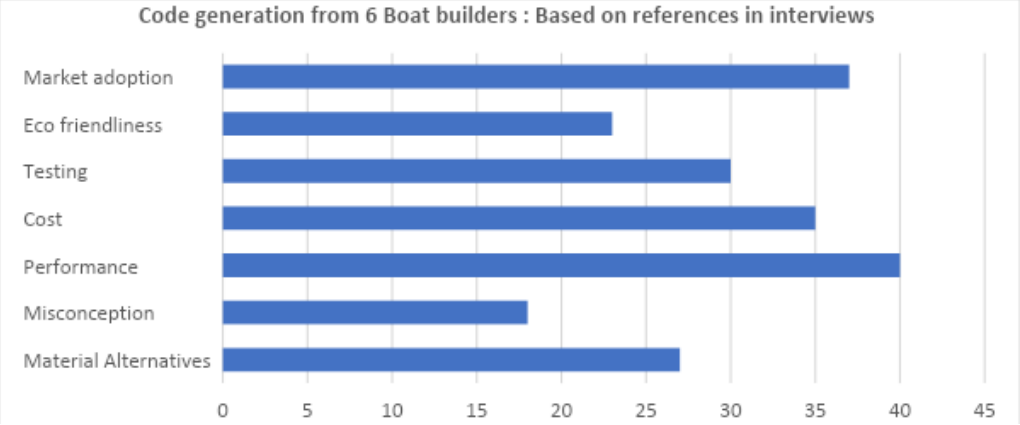


Figure 158: Code generation from 6 boat builders. Based on references during interviews

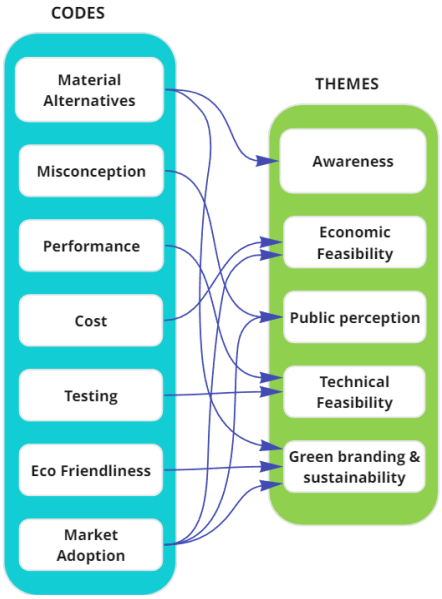


Figure 159: Matching codes with common themes

During the interviews with the boat builders, several questions about performance and testing were raised. In response, the researcher cited research evidence to validate the material used. An example of such a response is provided below:

Example:

" In the research article: Natural fibre composite energy absorption structures by Meredith et al. (2012), they found that natural fibres such as hemp and flax have a specific modulus at par with fibreglass. However, the tensile strength of hemp is lower than fibreglass fibre. Non-woven hemp-reinforced composites have better energy absorption on impact at lower speeds of 2.5m/s compared to chop-strand fibreglass composites, making them suitable for motorsports. The similar SEA (specific energy absorption) of both non-woven hemp (54.3 J/g) and carbon fibre (55.7 J/g) indicates the potential of hemp fibre in impact absorption".

Sample Interview Snippet 2: With Hemp Retailer

Researcher (at iHemp summit 2023, displaying samples)	**Hemp Retailer**
"Hello"	"What are these samples?"
"They are hemp fibre reinforced bio-composites panels made with bio resin".	"Wow, I love the finish on this. Where can I buy these? I am renovating my kitchen; I think it would go well on the wall against my kitchen counter."
"Sorry, it's not for sale. These samples were developed at the University as part of my research."	"I love the texture you have here. What are you researching on?"
"I am trying to understand the commercial possibilities of using hemp fibre reinforced composites like these in boat building."	"Well, we do have a lot of boat builders here. Can you share your contact details? Note down mine, too. Let me know when you start manufacturing this in bigger panels."
"Are you aware of hemp bio-composites like these?"	"I am seeing this for the first time. They look similar to the hemp skis displayed by Rubisco, right?"
"Yes, in fact, they are very similar. I am not sure what resins they have used, but we have used bio resins to make our laminates."	"I've worked with hempcrete, and they are in huge demand. If this is produced in bigger panels, it would work well in home interiors."

Table 9: Snippet of the discussion between the researcher and a hemp retailer

The codes and themes that were generated from the interview snippet presented in Table 9 are shown below.

Codes:

1) **Product Inquiry:** Asking about the possibility of purchasing the samples.
2) **Aesthetic Appeal:** Complimenting the finish of the samples.
3) **Personal Use Interest:** Mention of renovating the kitchen.
4) **Networking:** Request to exchange contact details for future reference.
5) **Lack of Awareness:** First-time seeing this specific type of hemp composite.
6) **Similar Products:** Comparison with hemp skis by Rubisco.
7) **Existing Experience:** Mention of previous work with hempcrete.
8) **Home Interior Applications:** Suggestion for use in home interiors.

Themes:

1) **Market Interest:** Combines "Product Inquiry," "Aesthetic Appeal," and "Personal Use Interest", highlights a genuine market interest in the hemp composite panels.
2) **Networking and Future Collaboration:** Includes "Networking", indicates the hemp expert's interest in keeping a relationship for future opportunities.
3) **Public Awareness and Product Familiarity:** Encompasses "Lack of Awareness" and "Similar Products", focuses on the hemp expert's familiarity or lack thereof with similar products.
4) **Prior Experience and Expanded Application:** Covers "Existing Experience" and "Home Interior Applications", indicates the hemp expert's background with hemp-based products and seeing new applications for them.

Example Analysis Table:

Key Statements	Code	Theme
"What are these samples?"	Product Inquiry	Market Interest
"Wow, I love the finish on this. Where can I buy these?"	Aesthetic Appeal	Market Interest

"I am renovating my kitchen; I think it would go well on the wall against my kitchen counter."	Personal use Interest	Market Interest
"Well, we do have a lot of boat builders here. Can you share your contact details?"	Networking	Future Collaboration
"I am seeing this for the first time. They look similar to the hemp skis displayed by Rubisco, right?"	Lack of Awareness	Awareness and product familiarity
"I've worked with hempcrete, and they are in huge demand."	Existing experience	Prior Experience and expanded application
"If this is produced in bigger panels, it would work well in home interiors."	Home interior applications	Prior Experience and expanded application

Table 10: Analysis of the conversation as pointers to build codes and themes

Final Code and Theme generation for 14 Hemp expert interviews and sample feedback:

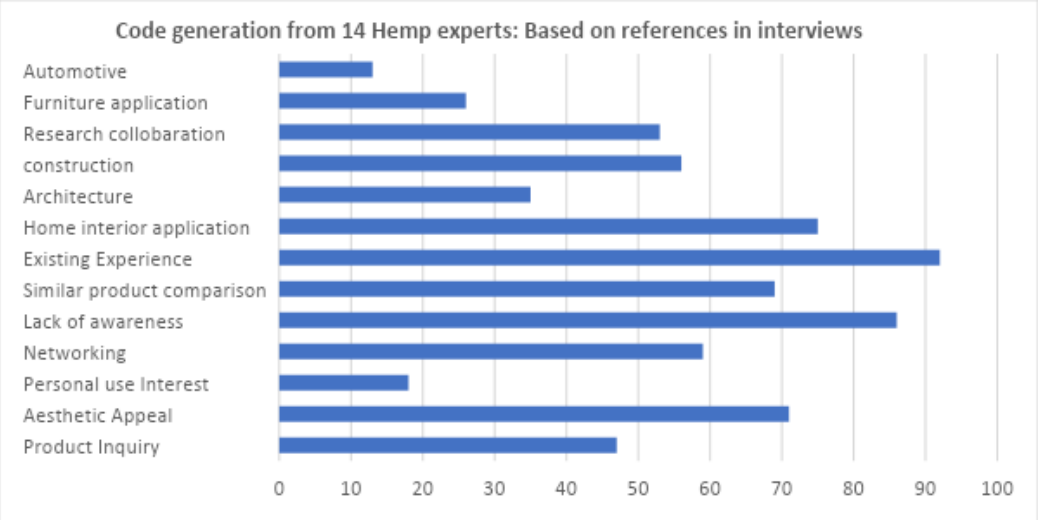


Figure 160: Code generation from 14 hemp experts, based on references in interviews

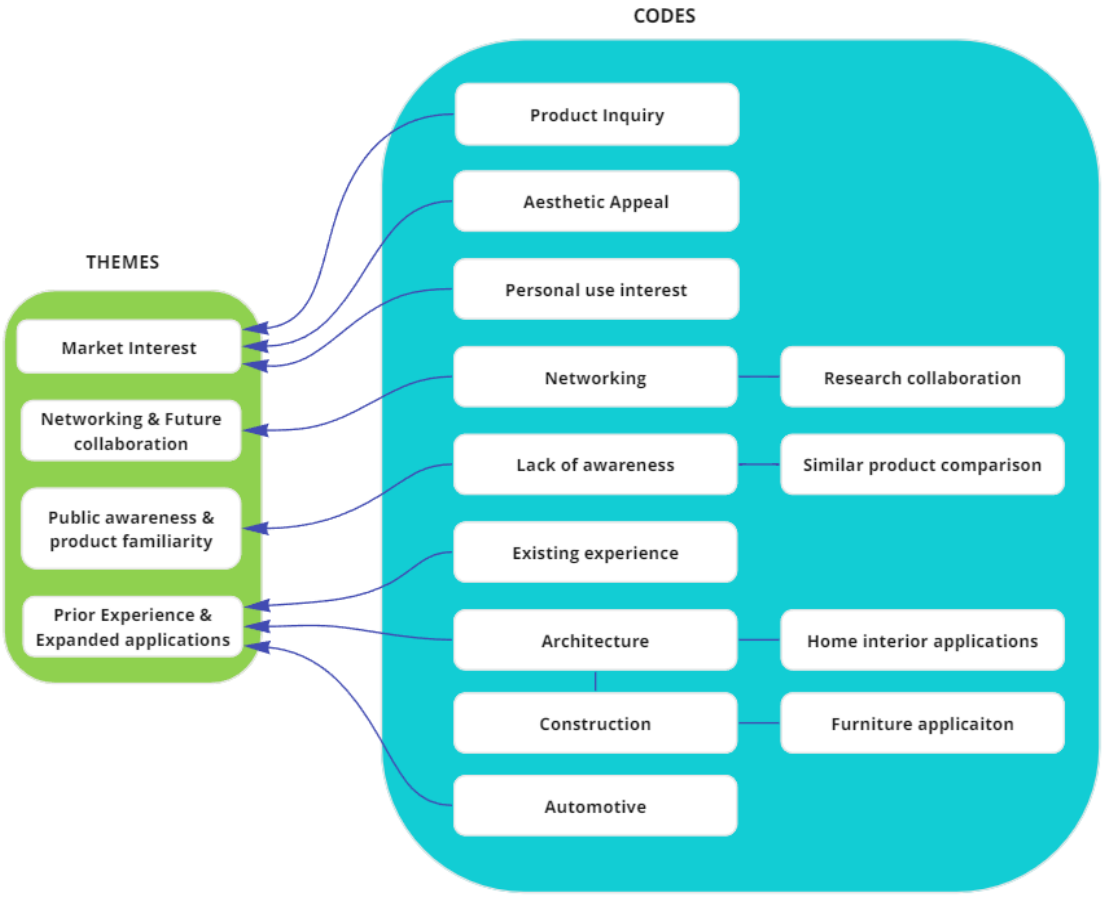


Figure 161: Matching codes with common themes

The codes and themes generated from the two participant groups (see Figures 159 and 161) were further analysed in order to develop and led to a combined themes. This is presented in the interview findings section.

4.3. COMMERCIAL VIABILITY AND SUSTAINABILITY

The primary objective of this study was to evaluate the commercial viability and sustainability of hemp bio-composites within Aotearoa New Zealand's boat building sector. However, the course of the research unveiled promising opportunities for broader applications across various industries within the country. The assessment of composites was contingent upon their alignment with specific industry benchmarks, including material properties and performance, cost-effectiveness, environmental impact, supply chain robustness, and adherence to regulatory standards. Gaining insights into how a product or material aligns with these criteria is pivotal in determining its practicality and potential for success within a particular industry and across the nation's broader economic landscape

4.3.1. Opinions and Findings

From the data analysis of the interviews and conversations around the sample it can be seen that the two participant groups had distinct concerns and interests. The boat builders were focused on technical performance and market adoption, whereas the hemp experts were primarily interested in collaborative efforts and alternative uses for the material. The willingness of the participants to collaborate directly mirrors the emerging status of the industry, where various experts and entrepreneurs are open to engaging in experimentation with bio composite materials. For the hemp experts, exposure to high-gloss and matte laminate finishes with hemp was a novel experience that garnered significant appreciation. Although they were not previously aware of hemp fibre-reinforced composites as an alternative to fibreglass, they showed curiosity about other potential applications. On the other hand, boat builders were aware that natural fibres could be used for composites, even though they were not necessarily aware of the existence and the properties of hemp fibre composites. After initial concerns regarding the use of hemp, these were soon dispelled on interaction with the samples, which created a sense of curiosity and genuine interest.

One interesting concern raised by a boat builder was related to the high cost of the bio-resin epoxy, which was about 1.5 times the price of the regular marine epoxy used by most boat builders. The researcher suggested the boat builder could continue to use regular marine epoxy combined with hemp-woven and non-woven fabrics and only gradually switch to bio resins based on demand. This was considered a welcome suggestion by the boat builder.

Based on the thematic analysis of the interviews with the boat builders and the hemp experts, here are the key findings from the identified themes:

Boat Builder Interviews:

Material Innovation:

- There was a general openness to exploring new materials like hemp bio-composites, but their willingness to switch to a new material depends on its performance.

- Specific attributes like stiffness and durability were identified as crucial factors in deciding the adoption of new materials in boat building.
- There was genuine interest in the bio-epoxy resin used, drawing parallels with their own epoxy used for boat building.

Market Potential:

- Cost emerged as a significant barrier to adoption as the costs of bio-resins and importing hemp fibre composites are higher than the current materials used.
- The value of branding for eco-friendly boats was recognised, which suggests that niche markets may be more receptive to hemp composite components.
- Participants commented that mass production could lead to price reduction and overall market acceptance.

Research and Development:

- There was interest in exploring collaborations and the possibility of creating sample components to test the material as participants, emphasised the need to have empirical data on the performance of hemp fibre composites before they would be willing build an entire boat with this material.

Hemp Expert Interviews:

Market Interest:

- There was an immediate and tangible interest in hemp composites for different applications like construction, architecture, home interiors and automotive sector, signalling potential market opportunities outside of boat building.

Networking and Future Collaboration:

- The hemp experts were interested in connecting and collaborating in the future, which indicates potential avenues for market penetration and development.

Public Awareness and Product Familiarity:

- There was limited awareness about hemp composites, but the experts were able to draw parallels with similar products, suggesting that education may be needed to ease market entry.

Prior Experience and Expanded Application:

- The experts had prior experience with hemp-based products like Hempcrete, hemp wood, hemp plaster and hemp fabrics, indicating that there might be a quicker acceptance and understanding of the product's potential in markets where hemp products are already in use.

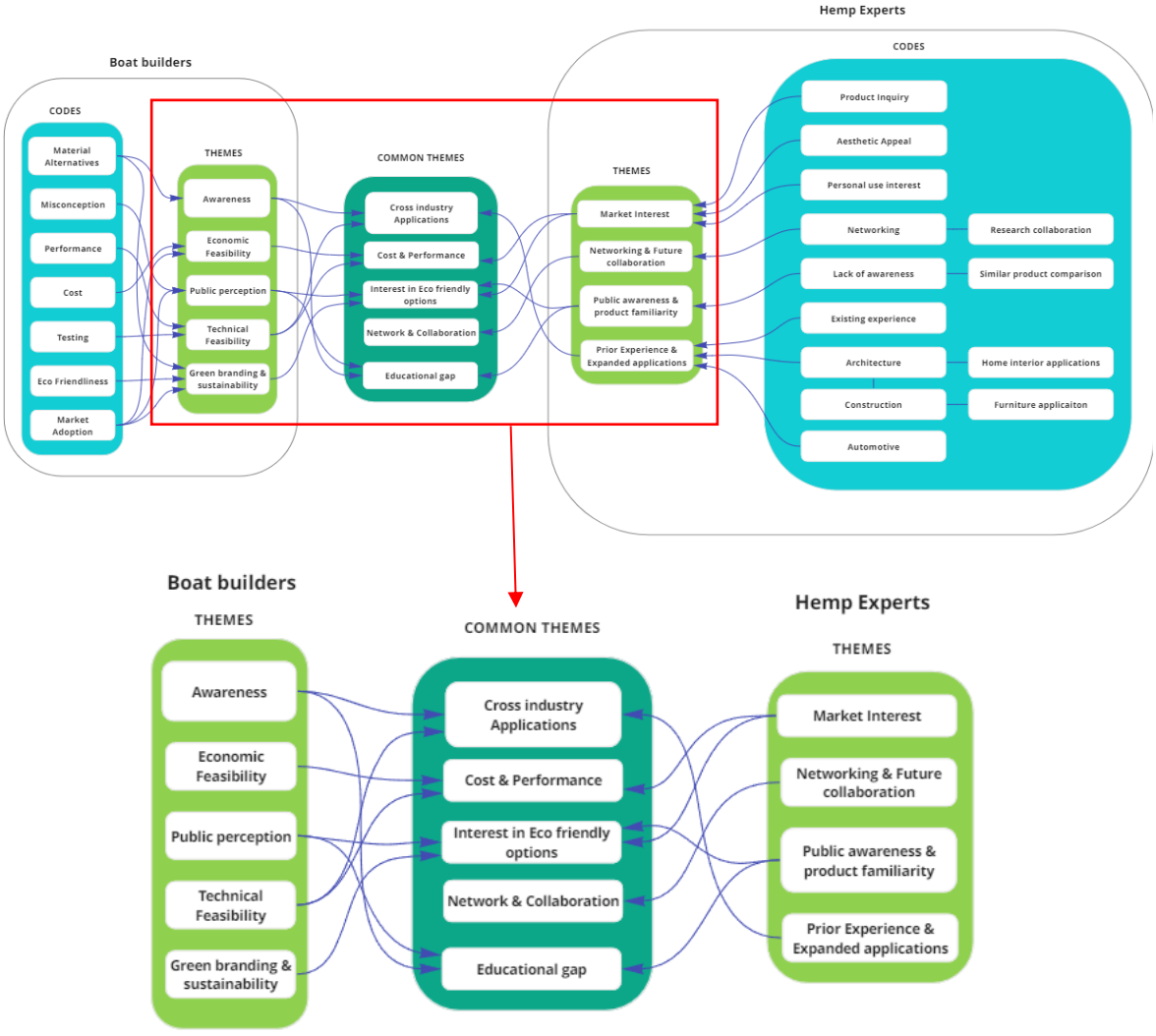


Figure 162: Arriving at common themes from both boat builders and hemp experts

Core Themes and Findings:

1. Cross-Industry Applications: Participants from both groups suggested hemp bio-composites have potential applications beyond boat building. While the boat builders considered it for specific components of the boat, the hemp experts saw potential in other sectors.
2. Cost and Performance are Key: Regardless of the industry, the cost and performance of the material were regarded as major factors affecting its adoption.
3) Interest in Eco-friendly Options: There was an underlying interest in sustainable, eco-friendly materials, although this must be balanced with cost and performance concerns.
4) Network and Collaborate: Participants from both interview groups highlighted the importance of networking for both market entry and development. There was a willingness to explore, but partnerships and collaborations might be key to advancing commercial applications.
5) Educational Gap: There was a need for increasing awareness and understanding of hemp bio-composites. Existing familiarity with other hemp products could serve as a gateway for new product line.

4.3.2. Regulatory and Production Challenges

The prevailing assumption at the outset of this research was that regulatory constraints significantly hindered the cultivation and adoption of hemp fibre. This notion was derived from preliminary studies that suggested bureaucratic roadblocks were a primary concern. However, this perspective shifted markedly following a series of presentations at the iHemp summit and from interviews with experts in the hemp industry. Contrary to the initial belief, these experts clarified that in Aotearoa New Zealand, no formidable legal obstacles impede the growth of industrial hemp for fibre use. As it emerged, the real challenge was not in the cultivation itself but in the subsequent processing stages, particularly concerning the transformation of hemp fibre into usable fabric.

A significant revelation from these interactions was the considerable financial investment required to establish a fully operational hemp fibre processing plant. An industry leader and participant in this study underscored the necessity of a substantial capital influx, estimating the requirement to be several million dollars. She elaborated on the array of specialised machinery essential for the various stages of processing hemp fibres into yarn and fabric. This machinery, integral to the conversion process, is available for purchase from various international markets, including Europe, Australia, and China.

The cost of this machinery is a critical factor to consider, with the most budget-friendly options coming from China, ranging between $15,000 and $250,000. However, it was noted that these more affordable machines often fall short in terms of durability and reliability, leading to rapid malfunction and eventual obsolescence, thereby resulting in substantial financial losses for the investors. This aspect further complicates the decision-making process for potential investors.

During a particular discussion with a pioneer in the hemp industry at the iHemp summit, the conversation veered towards the scale of investment necessary for establishing a robust and sustainable hemp fibre supply chain within Aotearoa New Zealand. The figures mentioned pointed towards an initial investment ranging from 3 to 5 million NZD, potentially escalating to as much as 15 million NZD. This level of financial commitment would not only cover the cost of the machinery and its importation but also ensure the establishment of a production facility capable of converting hemp fibre into high-quality fabric, thus addressing one of the critical gaps in the current hemp industry infrastructure in Aotearoa New Zealand.

4.3.3. Price Analysis and Challenges

An exploration of the economic factors, beyond the technical qualities of the materials was conducted to ascertain the viability of hemp fibre and bio-resin epoxy compared to traditional fibreglass and marine epoxy. The price analysis was based on the pricing of the materials purchased to make the sample prototypes (import cost to New Zealand was not considered as the material batch size was small). This analysis is important to comprehend the cost implications of adopting these sustainable alternatives. The study involved a price

comparison, adjusting figures to a standard measure for ease of analysis. Prices were converted to New Zealand dollars (NZD) as of 25th October 2023:

Hemp Fibre:

1) 100gsm hemp non-woven: 1.3 £/m^2 (Easy composites, UK) to 3.21 €/m^2 (Eco technilin, France): 2.7 NZD/m^2 to 5.81 NZD/m^2
2) 150 gsm hemp non-woven: 1.3 £/m^2(Easy composite, UK) to 3.5 €/m^2 (Eco technilin, France): 2.7 NZD to 6.33 NZD
3) 135 gsm hemp woven: 2 AUD/ m^2 (Colan, Australia): 2.18 NZD / m^2
4) 140 to 430 gsm hemp woven: Rs 1300/ m^2 (from India): 26.74 NZD/ m^2

Fibreglass:

1) Fibre glass chop strand mat 225 gsm to 450 gsm: 6 NZD/m^2 (Resincraft, Aotearoa New Zealand) to 10 NZD/m^2 (Burnsco, Aotearoa New Zealand)
2) Fibreglass woven 100 gsm to 600 gsm: 8.9 NZD/m^2 (IFS, Aotearoa New Zealand) to 26.4 NZD/m^2 (Burnsco, Aotearoa New Zealand)

Bio Resin Epoxy vs Marine Epoxy: (Includes resin and hardener price)

1) Bio resin epoxy: 120 NZD/kg (Resincraft, Aotearoa New Zealand)
2) Marine epoxy: 85 NZD/kg (Resincraft, Aotearoa New Zealand)

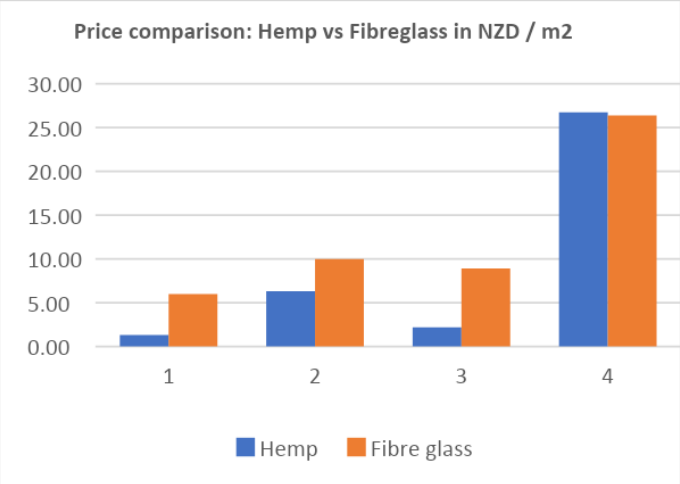


Figure 163: Price comparison of Hemp vs Fibreglass woven and non-woven fabrics

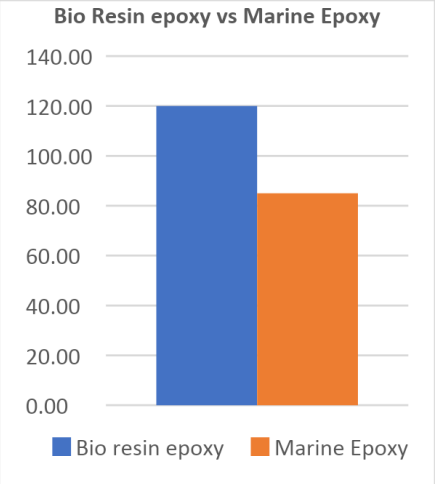


Figure 164: Price comparison of bio-resin epoxy vs Marine epoxy

This analysis did not include import costs to Aotearoa New Zealand, as these would vary based on import volume. However, these costs are expected to align closely with those associated with importing fibreglass. The comparison revealed that hemp fabric, notably the non-woven types, is considerably less expensive than fibreglass—however, the cost dynamics shift when considering epoxies. The bio-resin epoxy is about 1.5 times more expensive than the conventional marine epoxy. Yet, when these materials are combined to form composites, the lower cost of hemp fabric helps mitigate the higher price of bio-resin epoxy, leading to a more balanced cost equation.

It is critical to note that the fabrics used in this research represent a blend of textile-grade and composite-specific hemp materials. Developing specialised woven fabrics tailored for composite manufacturing with unique roving patterns is expected to influence the pricing structure differently. This diversity in fabric types and their respective costs is crucial in determining the overall feasibility and commercial viability of hemp fibre and bio-resin composites.

4.4. SUMMARY

This chapter highlights the growing interest in and potential of hemp bio-composites, particularly within the Aotearoa New Zealand boat building sector and beyond. The insights from key references in the literature review, such as Dokos (2013), Faruk et al. (2012a), Elseify et al. (2021), Barth and Carus (2019), Davis (2020), Müssig et al. (2020), and Marsh (2020) reflect a multifaceted view of the hemp composite market. This chapter shed light on global adoption trends, technological advancements, and economic implications in the realm of natural fibre composites. The chapter emphasised and reflected on the significance of hemp composites in diverse applications, highlighting their growing market presence and the optimistic outlook of governments and industries towards this sustainable material. Specifically, the thematic analysis responds to the literature's call for empirical insights into market readiness, regulatory challenges, and the environmental impact of hemp bio-composites.

CHAPTER 5: CONCLUSION

From conversations with the hemp industry experts as well as composites researchers, it was evident that the major reason why hemp fibre has not yet been embraced by the composites industry was the lack of supply. To quote a composites researcher during an interview session:

"It's a wonderful material. However, switching an entire composite's raw material to hemp fibre is not feasible for a manufacturer. Who is manufacturing it in such large quantities? Hemp isn't even as popular as flax! If the supply chain issue is resolved, we can consider this material. Until then, when using natural fibres for composite manufacturing, we'll stick to flax."

This is a common theme for most new bio- and eco-friendly materials entering the market. It shows how hemp-based materials will be adopted in industry. Performance expectations and cost considerations form the baseline for any initial interest. Environmental consciousness acts as an enhancer, especially in niche markets. Market adaptability can be a game-changer, broadening the scope of applications. Community and collaboration help in knowledge sharing and problem-solving, while awareness and education prepare the market for adoption. Achieving a balanced adoption of hemp bio-composites in industrial applications requires a multifaceted approach, addressing synchronised technical, financial, social, and educational factors.

During the process of sample sourcing, it became evident that obtaining the correct type of hemp yarn was exceedingly challenging. The market currently faces a shortage of woven roving hemp fabric and yarn, especially those designed for composite development. Additionally, materials such as hemp PLA were scarce, and bioplastics like hemp HDPE and hemp PETG were either unavailable or quickly sold out. This scenario highlights a significant demand for hemp bioplastics, yet the supply chain struggles to meet this growing need. However, as regulations on industrial hemp farming globally begin to relax and become more accommodating, this situation is expected to improve. Manufacturers investing in hemp bio-composites are now positioning themselves as future leaders in this emerging

market. The cost of woven hemp rovings is anticipated to be lower than current estimates, and processes like bleaching are likely unnecessary, focusing solely on weaving rovings.

Developing exploratory composite panels with sandwich cores, such as those involving mycelium composites, cork, and Nomex, has shown considerable promise. OC Tenders' interest to replace fibreglass with hemp composites, particularly as a core material for carbon fibre boats, marks a significant and positive shift. The potential for creating hybrid composites that blend fibreglass and hemp fibre could facilitate a smoother transition to bio-based materials. The vibration absorption properties of hemp composites might be enhanced by incorporating additional core materials like mycelium, cork, or Nomex.

At the outset of this research, there was a perception that setting up hemp-related businesses might be challenging. However, feedback from interviews with hemp industry experts revealed that starting a business in hemp fibre farming and manufacturing is easier than dealing with hemp seeds and flowers. This insight indicates a clear potential for commercialising hemp bio-composites, replacing fibreglass composites within the boat building industry and expanding their applications to other sectors.

With the proper financial backing from entities such as Callaghan Innovation, a consortium of hemp entrepreneurs and companies, could provide the necessary funding to establish a production plant. Such a cooperative approach is already prevalent in Aotearoa New Zealand's boat building industry, where companies often specialise in manufacturing specific boat components. A similar model could be effectively applied to the hemp sector.

Aotearoa New Zealand boat builders, known for their innovative spirit, are generally open to adopting hemp-based bio-composites, provided they are competitively priced compared to fibreglass. If adequately promoted, the industry's familiarity with flax may make it easier for hemp fibre to be accepted.

The trajectory of hemp fibre adoption may parallel the evolution seen in the automotive industry's shift towards electric vehicles—from horse-drawn carriages to petrol and diesel vehicles, then hybrids, and finally to the widespread acceptance of electric cars. A similar progression is envisaged in boat building, transitioning from fibreglass composites to natural fibre composites. In the current industry landscape, hemp-based bio-composites are

unlikely to replace fibreglass completely. Instead, a gradual shift is expected, where both materials are used concurrently, eventually leading to a comprehensive transition towards hemp fibre composites.

In essence, the following understanding emerges regarding the sustainability and commercial viability of hemp bio-composites in Aotearoa New Zealand's boat building industry:

1. **Sustainability Prospects**:

    - **Environmental Benefits**: Hemp bio-composites present a more environmentally friendly alternative to traditional materials like fibreglass. Hemp cultivation sequesters carbon dioxide, and the material is biodegradable, reducing environmental impact.

    - **Performance Attributes**: Hemp bio-composites demonstrate comparable strength and durability to traditional materials, which is crucial for sustainability in marine environments.

    - **Industry Response**: There is an increasing interest in sustainable and eco-friendly materials within the boat building industry, driven by environmental concerns and consumer demand.

2. **Commercial Viability**:

    - **Cost Challenges**: A significant barrier to adopting hemp bio-composites is their cost, especially concerning the price of bio-resin epoxy. However, the material cost of hemp fibre is generally lower than fibreglass, offering some economic advantages.

    - **Market Interest**: There is a strong market interest in hemp bio-composites for various applications, extending beyond boat building. This diverse applicability can drive demand and production scale, potentially lowering costs.

- **Supply Chain Issues**: A major constraint is the lack of a robust supply chain for hemp fibre processing and fabric production in Aotearoa New Zealand. Establishing local production facilities could reduce import costs and make hemp bio-composites more economically viable.

- **Technical Challenges**: The performance of this material, in comparison to traditional fibreglass composites, requires more validation and a thorough analysis by experts in the field. True adoption will begin with real-world test data.

3. **Recommendations for Improvement**:

    - **Enhancing Supply Chains**: Developing local processing capabilities for hemp fibre would significantly contribute to the economic viability of hemp bio-composites.

    - **Reducing Costs**: Innovations in manufacturing and material processing, as well as economies of scale, could help reduce costs, making hemp bio-composites more competitive.

    - **Research and Development**: Further research into improving the material properties of hemp bio-composites and exploring new applications can expand their market potential.

4. **Broader Industry Implications**:

    - **Cross-Industry Adaptability**: The potential use of hemp bio-composites in various industries suggests a broad scope for commercialisation, not limited to boat building.

    - **Educational and Awareness Programs**: Increasing public and industry awareness about the benefits of hemp bio-composites can stimulate market demand and acceptance.

5.1. RECOMMENDATIONS FOR FUTURE RESEARCH

A notable limitation of this study was the insufficient demonstration of the mechanical properties, especially the strength, of the fabricated samples. This issue was repeatedly raised as a concern by boat builders during the interviews. The absence of mechanical testing was mainly due to time constraints, which limited the opportunity for a comprehensive investigation. Moreover, the study did not thoroughly explore the possibility of integrating hemp with other plastics and biomaterials. This limitation was also primarily due to time restrictions that constrained the scope of exploration in this area.

The future of hemp-based composites holds immense potential. The exploration of hemp-based materials like PLA, PP, and HDPE are in its early stages. Composites made from hemp laminates with mycelium cores are showing great promise, particularly as alternatives to fibreglass panels with Styrofoam cores. This burgeoning area of research has the potential to unlock new applications in the global market. Furthermore, certain fungal strains have been identified to produce glycerol, a key ingredient in epoxy resins. Developing more eco-friendly epoxy variants leveraging this natural process could significantly boost global demand for these sustainable materials.

The following are key recommendations for future research that could significantly contribute to the field of hemp bio-composites in the boat building industry, as well as in other applications:

1. **Performance and Durability Testing in Marine Environments**:
    - Detailed studies on the long-term performance and durability of hemp bio-composites in marine environments with a focus on water absorption, UV resistance, and wear under various climatic conditions.
    - Comparative analyses of hemp bio-composites with traditional materials like fibreglass and carbon fibre under similar conditions.
2. **Economic Viability and Market Potential Studies**:
    - In-depth industry-wide market research studies to understand the demand for eco-friendly and sustainable boat building materials.
    - Cost-benefit analyses of using hemp bio-composites in boat building, considering factors like production costs, maintenance, and lifecycle analysis.

3. **Supply Chain Development and Material Sourcing**:

    - Investigating and developing a robust supply chain for sourcing high-quality hemp fibres and bio-resin epoxies, particularly in Aotearoa New Zealand.

    - Exploring the possibility of local production of hemp fibres and bio-resins to reduce import costs and foster the local hemp industry.

4. **Technological Innovations in Composite Manufacturing**:

    - Research on advanced manufacturing techniques for hemp bio-composites, such as 3D printing, automated layup processes, and resin infusion techniques.

    - Development of hybrid composites that combine hemp with other materials (like carbon or glass fibres) for enhanced properties.

5. **Environmental Impact and Sustainability Assessments**:

    - Comprehensive life cycle assessment (LCA) of hemp bio-composites to quantify their environmental benefits compared to traditional materials.

    - Studies on the recyclability and end-of-life options for hemp bio-composites to promote circular economy principles.

6. **Regulatory Framework and Standardisation**:

    - Research on existing regulatory barriers and development of a framework for the standardisation of hemp bio-composites in the marine industry.

    - Collaboration with regulatory bodies to establish guidelines and certifications for using hemp bio-composites in boat building, similar to the construction industry that uses green building and material certifications.

7. **Consumer Perception and Market Acceptance**:

    - Studying consumer perceptions and acceptance of hemp-composite boats, focusing on aspects like aesthetics, performance, and environmental impact.

    - Marketing strategies to promote the adoption of hemp bio-composites in the boat building industry and beyond.

    - Market trend analysis includes trends on sustainable materials in the marine industry and what influences their adoption.

    - Global context study with respect to Aotearoa New Zealand's future role and economic impact of this adoption.

8. **Collaborative Industry Partnerships**:

    - Establishing partnerships between academia, industry, and government to foster innovation and commercialisation of hemp bio-composites.
    - Exploring government funding channels for Research and Development.
    - Initiatives to encourage collaboration between hemp growers, composite manufacturers, and boat builders for integrated development.

9. **Innovative Applications Beyond Boat Building**:

    - Exploring the use of hemp bio-composites in other industries such as automotive, construction, and aerospace for diversified applications.
    - Research on customising hemp bio-composites for specific applications with tailored properties like strength, stiffness, and weight.

10. **Educational and Awareness Programs**:

    - Developing educational programs and workshops to increase awareness about the benefits and potential of hemp bio-composites.
    - Promoting research findings and successes to the public and potential industry adopters to encourage the use of sustainable materials.

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Appendix A –



The Researcher trying out laminating on Styrofoam after training by Senior technicians at AUT



Cutting Hemp bio-composite samples to size



BOATWORLD BOATWORLD BOATWORLD BOATWORLD BOAT

BIO-COMPOSITE FOR BOATS

Industrial Designer Gautam Madhavan Nair, a researcher at AUT, is currently exploring the commercial viability of using bio-composites in boatbuilding in New Zealand.

Gautam, working under the guidance of Dr. Sangeeta Karmokar, is investigating practical applications of hemp fibre reinforced bio-composite panels. As part of his research, Nair has experimented with a range of natural fibres and varying amounts of bio-resin. So far, hemp fibre is showing the most promise, producing commercially viable hybrid panels suitable for boat building and other applications.

Nair's work has already been endorsed by Northland boat builder OC Tenders, one of the first companies in Australasia to adopt a hemp fibre-reinforced panel in their boats. OC Tenders CEO Russell Carlyon says they are looking forward to exploring potential ways to replace the fibreglass used in their boats with bio-composite hemp fibre panels.

Current bio-composite panels have PVC cores, though Nair is exploring cores made from natural materials, as well as 3D-printed honeycomb cores. Panels are sheathed in woven hemp fibre cloth and resin-infused with a mix of 30% bio-resin and regular epoxy.

The hybrid bio-composite panels are stronger and lighter than fibreglass, but slightly heavier, slightly less strong and with more flex than carbon fibre. Natural fibre bio-composites also make great acoustic panels, says Nair.

Nair is looking to interest more New Zealand boat builders in adopting bio-composites. He's keen to hear from any boat builder willing to learn more about bio-composites and their possible applications. His contact details are listed below.

Gautam Madhavan Nair,
mn.gautam@gmail.com

L-R: Russell Carlyon (CEO, OC Tenders), Gautam Madhavan Nair and Matt Loveridge (OC Tenders).

BELOW: Sample bio-composite panels.



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BIO-COMPOSITE FOR BOATS

LETTERS TO THE EDITOR

REMEMBERING *UWHILNA*

COMPLIANT OR NOT?

Boating New Zealand 21

Article on current research by Boating NZ magazine Nov issue Pg 21



The senior technician at OC Tenders explained the moulding process and issues when removing casts.





Sr Technician at OC tenders explaining the use of a small carbon fibre template to align the fabric to
The corners of the mould.





Sr Technician at OC tenders checking the temperature of the composite component during Vacuum infusion process.



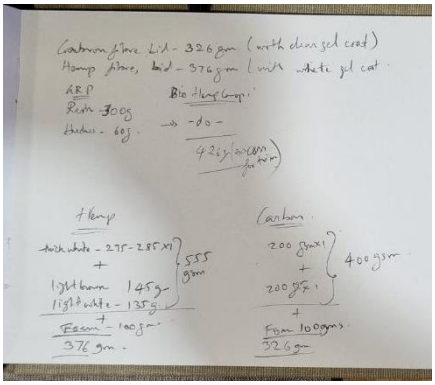
Sr Technician at OC tenders testing the bending and flexing of the component after finishing.



Final set of samples



First damaged hemp PLA 3D print



Fibre and foam weight calculation of Hemp composite vs carbon fibre composite



The final list of fabrics tested with OC tenders

Appendix B –



Invitation to participate in research sent to participants.

Auckland University of Technology Ethics Committee (AUTEC)

7 July 2023

Sangeeta Karmokar
Faculty of Design and Creative Technologies

Dear Sangeeta

Re Ethics Application: **23/138 From Seed to Sail: The commercial viability and sustainable future for New Zealand boat building with Hemp bio composites.**

Thank you for your responses to AUTEC's conditions.

Your ethics application has been approved for three years until 7 July 2026.

Non-Standard Conditions of Approval

1. In the Information Sheet edit the introduction as the researchers name is all that is required (i.e. not their role or the title repeated), remove the ACC statement and the offer of counselling.

Non-standard conditions do not need to be submitted to or reviewed by AUTEC unless requested but must be completed before commencing your study.

Standard Conditions of Approval

1. The research is to be undertaken in accordance with the Auckland University of Technology Code of Conduct for Research and as approved by AUTEC.
2. All public facing documents must have the AUTEC approval number and be of a high standard of spelling and grammar. Dates on the Information Sheet(s) and Consent Form(s) must be consistent.
3. Any amendments to the project must be approved by AUTEC prior to being implemented.
4. A progress report is due annually on the anniversary of the approval date.
5. A final report is due at the expiration of the approval period, or, upon completion of project.
6. Any serious or adverse events must be reported to AUTEC, this includes unforeseen issues that might affect continued ethical acceptability of the project.
7. AUTEC grants ethical approval only. You are responsible for obtaining management permission for access from any institution or organisation at which your research is being conducted and you need to meet all ethical, legal, public health, and locality obligations or requirements for the jurisdictions in which the research is being undertaken.

The application number and title need to be referenced on all correspondence related to this project.

All forms are available online http://www.aut.ac.nz/research/researchethics

For any enquiries, please contact ethics@aut.ac.nz
(This is a computer-generated letter for which no signature is required)

The AUTEC Secretariat
Auckland University of Technology Ethics Committee

Cc: mws9912@autuni.ac.nz; mn.gautam@gmail.com

Ethics committee approval letter