CHEMICAL MODIFICATION OF TIMBER DECKING: ASSESSING THE PARAMETERS OF ACCEPTABILITY

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ABSTRACT

The criteria for accepting or rejecting a technology extend beyond the intrinsic properties of the finished product such as physical performance. There are also extrinsic factors such as the history of the product and trust in the manufacturers and suppliers, as well as the perceptions and risk management strategies of various stakeholder groups. A methodology was trialled to take into account the extended supply chain of the product, while simultaneously engaging stakeholders to determine and to understand their perceptual frameworks. Three pine decking products manufactured using different amounts and types of chemical modification were compared using life cycle assessment and the comments of 114 respondents from six stakeholder groups in New Zealand. The results of the perceptual research include a quadrant diagram which allows a visual comparison of the responses of different stakeholders to actual or hypothetical products, aiding the identification of when and why certain technologies may be disqualified from acceptability or become the topic of public debate.

Keywords: chemicals, wood, innovation, acceptability, industrial ecology

INTRODUCTION

Recent advances in the biological sciences, combined with economic initiatives in certain regions, are helping to fuel an increasing worldwide focus on renewable and eco-efficient resources (Singh *et al*. 2003). This would seem to provide huge opportunities for growth in the global production and consumption of bio-based products. Yet a key requirement for the adoption of bio-based products continues

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to be that they are comparable to alternative products in terms of both cost and performance. Organic products such as wood are generally, by their nature, more susceptible to degradation and deterioration than inorganic products. They consequently often require some form of treatment to enhance attributes such as longevity, if this is a desired goal. Perceptions about the environmental or social impacts of such treatment may seriously jeopardise the acceptance and uptake of organic products.

The criteria for accepting or rejecting a technology extend far beyond the physical properties, functionality, and perceived benefits of the finished products. Concerns about the sustainability of the source materials, the environmental and social hazards pursuant to manufacture, use, and disposal of the products, and the consistency of all of these with social values, are all part of the equation as well. People may, for example, reject a product which uses materials sourced from tropical rainforests or from genetically modified organisms (Marris 2001; Walter & Killerby 2004). People may also reject organic products which have been treated with chemicals such as arsenic, which has a reputation in popular culture as being highly poisonous, no matter how tightly such chemicals have been bound into the product. For this reason, a full deliberation about the acceptance and uptake of technologies should realistically consider not only the finished product but the entire industrial ecology of the product. An industrial ecology perspective embraces the extended supply chain of the product, from the materials and processes used in manufacture through to disposal (Allenby 1994; Kleindorfer & Snir 2001). In considering the industrial ecology of the product, however, the emphasis should not be exclusively on the physical materials and processes. It is people's reactions to these materials and processes which will ultimately endorse or preclude a technology.

In order to evaluate how a full appraisal of the potential impacts of new technologies could feasibly be implemented, the New Zealand research organisation Scion, in conjunction with Unitec New Zealand, undertook research using chemically treated pine decking as an initial case study. This case study facilitated a comparison of three bio-based products made from exactly the same species for exactly the same end use but differing in the type and amount of chemical modification used. The three chemical modification technologies assessed were copper chrome arsenic (CCA), acetylation, and thermal treatment. A life cycle assessment was undertaken for each decking product in order to provide a comparison of the potential environmental impacts relating to the manufacture, use, and disposal of the same quantity of each material (De Smet *et al.* 1996; Maplesden *et al.* 2004). Simultaneously, a total of 114 respondents from six different stakeholder groups were asked to evaluate the three technologies based on physical samples of the finished product and an overview of known information relating to the industrial ecology of each product. The intention of the research was not to determine how many people in the population held certain opinions or preferences about particular technologies, but rather to ascertain how and why people in certain stakeholder groups may react differently to the same material and the same information. The results of the perceptual research are summarised in this paper.

Chemical Modification of Decking Products

The chemical modification technologies assessed in this case study were selected because of a contemporary dilemma within the timber construction industry. For the past 50 years or so, the primary means for chemically treating *Pinus radiata* D. Don grown in, and exported from, New Zealand has been the use of CCA. This involves high-pressure saturation of the wood with an acidic aqueous solution of copper, chromium, and arsenic. After drying, this solution is fixed into the wood (Smith & Shiau 1998). Such treatment has been highly successful in terms of enhancing longevity and being cost-effective. In recent years, however, CCA-treated timber has been banned or phased out of some domestic applications in Europe, the United States, and Australia (Vlosky & Shupe 2002). This action has ostensibly been prompted by public concerns about the exposure of children to timber treated with arsenic, with particular emphasis on wooden surfaces such as decks and children's play equipment (Vlosky & Shupe 2004b). A background issue is concern by regulatory authorities regarding the disposal of large quantities of CCA-treated timber, together with lack of knowledge about the actual wood treatment process or appropriate disposal. Burning of the timber releases arsene gas, and there are concerns that inappropriate burial of large quantities of discarded timber in landfills could result in the slow leaching of arsenic and chromium into the soil and groundwater (Sinclair & Smith 1990; Smith & Shiau 1998; Alderman *et al.* 2003; Jambeck *et al.* 2003; Donovan & Hesseln 2004; Vlosky & Shupe 2004a).

As concern has grown about the current regime for chemically modifying timber, there has been a move toward alternative products and new technologies. Lack of familiarity with alternative treatments inhibits their uptake, however, especially when problems arise. During the 1990s, for example, there was a rapid increase in the use of untreated kiln-dried timber in New Zealand. This was followed, within only a few years, by a public outcry when new timber-frame homes began leaking and rotting. It was found that untreated kiln-dried pine had been selected and used as a structural material in houses with modern designs that allowed more water into the roof and wall but did not allow such water to escape (Yates 2003). Known colloquially as Leaky Building Syndrome, this has led to the situation where there is now probably as much, if not more, concern in New Zealand about lack of chemical treatment of timber as there is about chemical treatment.

The dilemma in the New Zealand timber industry is that new and novel products are marginalised through fear of the toxicity from treatment on the one hand and fear of a lack of performance through lack of treatment on the other. Many consumers probably continue to look for building materials which have low chemical input but also are seeking assurances about performance, and so are opting for inorganic products. Regulators may be seeking assurances about the proven ability of treatments to meet new performance criteria. This situation raises the question as to what the parameters of acceptability are for new bio-based products with regard to chemical modification. How do we ascertain if and when different stakeholder groups are going to perceive problems with the treatment used?

Research Procedures

Focus groups, stakeholder interviews, and workshops were used to gain a preliminary understanding of the current thresholds of acceptability for chemicals in outdoor decking in New Zealand. In order to stimulate discussion about issues relating to chemical treatment of wood, all of the respondents were shown examples of three decking products with different amounts and types of chemical modification. One prompt was a sample of CCA-treated *P. radiata*, representing the existing base technology. The other two prompts were similar-sized pieces of *P. radiata* which had been treated with acetic anhydride (acetylated pine) and high-pressure steam (thermally treated pine).

Given that two of the timber treatments being considered were not yet on the market in New Zealand, respondents were invited to handle and examine the samples. They were also all required to read a standardised card for each product outlining known and/or hypothetical benefits and problems associated with its manufacture, use, and disposal. These three cards (Appendix 1) provided fuller information than consumers would currently have access to. The rationale for this was that we were seeking to ascertain how people in different stakeholder groups may react to issues relating to the entire life cycle of the product should this come to their attention through media and public debate. The two products that were not yet on the market were given hypothetical relative price differentials so as to compare the three products as if they were actually on the market. In terms of the source material for all three products, they were described as being sourced from sustainably managed plantation forests. Almost all of New Zealand's domestic timber supply is sourced from plantation-grown exotic species, which has allowed the majority of the remaining indigenous forest estate to be reserved from harvesting.

In order to scope the range of concerns that people currently had about chemical modification of decking, four focus groups (n=38) were held in November 2004. Two were hosted in the north of the country and two in the south, allowing any differences due to climate and culture to be taken into consideration. Ten respondents were invited to each, although two people failed to turn up at one of the groups.

All of the respondents were subscribers to an organisation called ConsumerLink, making themselves available for participation in surveys on a regular basis. A condition of participation in our focus groups was ownership of a deck. Two of the respondents in each group were also either a builder or an architect. This deliberate group composition stimulated a natural discussion among the respondents, the public expressing their concerns while also listening to and consulting the professional opinions of the industry representatives. The researchers were consequently able to observe the discussion and respond to queries, rather than simply facilitating a dialogue between themselves and the respondents. During the meeting each respondent also completed a short written questionnaire and they were then invited to comment upon the questions. This allowed any major omissions to be identified prior to the next stage of the research.

After analysis of the data derived from the focus groups, interviews were held with representatives from six stakeholder groups. A total of 114 people were interviewed between February and August 2005. The stakeholder groups represented included: chemistry, wood product, and environmental scientists involved in increasing the range of technologies available (n=19); business people involved in developing and marketing the new technologies (n=15); influencers, such as Government policy regulators and media, involved in filtering the options available (n=17); selectors, such as architects and builders, potentially involved in specifying appropriate materials to homeowners (n=19); consumers, who have to live with the new products (n=30); and Maori consumers, potentially critiquing bio-based products from a unique indigenous cultural perspective Of the 114 respondents, 70 were therefore interviewed in their professional capacity and 44 as consumers. The majority of respondents (64%) were male, with a particularly high bias toward men among the architects and builders (89%) and scientists (79%). In contrast, there was a higher representation of women (59%) among the influencers. The selection of both the consumers and the professional respondents was made using a snowball methodology, whereby friends or colleagues who had decks or were employed in a desired profession were identified and contacted. Larger sample sizes, random selection, and quotas for gender were not deemed necessary for this phase of the research, which was looking at how and why various stakeholder groups were reacting to the same stimuli, rather than the representation of these perceptions across the population. Furthermore, some of the stakeholder groups, such as the producers/scientists, have a fairly small population in New Zealand.

The issue of chemical modification of timber was in the news throughout the time that the interviews were administered, raising the profile of certain issues. The main issue in the media was continuing editorials about the so-called Leaky Building Syndrome in New Zealand and changes to building requirements being introduced in response to this. Other issues included soil contamination from CCA-treated posts buried on former horticultural land in the Marlborough and metropolitan Auckland regions. There was concern amongst home-owners in the latter area that the publication of information about such soil contamination would have a marked detrimental effect on their property values.

After analysis of the interview results, identifying any marked differences between the groups of respondents, two workshops (n=20) were held in November 2005. Representatives from the scientists and architects (selectors) were invited to one, and representatives from the business community and regulatory authorities (influencers) were invited to the other. There they were presented with the findings regarding respondent reactions to the three technologies, together with a comparison of some environmental metrics for each derived using life cycle assessment (LCA) methodologies (Maplesden *et al.* 2004). The workshops provided an opportunity for representatives from one stakeholder group to consider why the respondents from their group answered the way that they did, as well as why the other group represented held a significantly different view. The representatives then shared their deliberations, allowing them to see how the other group thought they were thinking and how the other group was actually making their decisions. Finally, the workshops also provided an opportunity to see how robust their respective views were in response to the additional scientific data obtained through the life cycle assessment.

RESULTS

Parameters of Acceptability

The initial focus groups helped identify 17 criteria that respondents considered when selecting or specifying appropriate materials for a new deck. Some of these issues related to where the materials came from and how they were made. Other issues related to the in-service performance of the materials, or to their eventual disposal or recycling. Specifically, these 17 criteria were, in no particular order of importance: low cost (initial outlay); low maintenance costs; durability; adequate stiffness and strength; no warp, twist, or bow; family health and safety; desirable appearance; natural; sustainably sourced raw material; minimal waste created in production; minimal waste created in disposal; recyclable; low energy input in production; low chemical input in production; low emission of gases from newly manufactured wood; proven technology; and trust in the manufacturer.

The interview respondents (n=114) were all asked to rate how important these issues were to them when they were thinking about building a new deck. A Likert-like scale was used, where a rating of 1 indicated that the issue was very important and 5 indicated that it was very unimportant. Overall, the most important issues were that the product was durable (mean=1.32) and did not have an undue negative impact on family health and safety (1.38). Other major concerns were that there was no warp, twist, or bow (1.48), it had adequate stiffness and strength (1.53) and low maintenance costs (1.68), it was a proven technology (1.89), had a desirable appearance (1.95), and a low cost (2.06) in terms of initial outlay. These results accord with studies conducted in the United States concerning the key selection criteria of homeowners and builders (Smith & Sinclair 1990; Cohen *et al*. 1992; Donkor *et al*. 2003).

Responses to other open questions reinforced the statement that low cost was not the number one concern. So long as an alternative was not exorbitantly expensive, its relative merits would be considered. Having said this, we are aware that there is a tendency for respondents to understate the importance that they attach to price and overstate the importance of what they feel that the researchers may be interested in.

Of slightly lesser importance to the respondents were that it was a sustainably sourced raw material (2.09), they had trust in the manufacturer (2.14), there would be minimal waste created in disposal (2.21), and the product was recyclable (2.30). The difference between these and those identified as more important is that these all have to do with the production and disposal rather than in-service performance. Such issues, while still important, were not at the forefront of people's minds when they were thinking about materials to purchase. In other words, of greatest concern were the criteria which are essentially intrinsic to the material, such as strength and stability. There are, however, various factors which, although not quite as important, are still being weighed up in considering the acceptability of the product. These factors may be called extrinsic, being issues such as history and trust. Other issues which were similarly relegated to secondary importance were low chemical input in production (2.32), minimal waste created in production (2.37), the product being natural (2.38), low emission of gases from newly manufactured wood products (2.49), and low energy input in production (2.53). In other words, the issue of chemicals in wood was somewhat important, but of greater importance was the influence that these chemicals would have on the primary parameters of acceptability — in-service performance and family health and safety.

After examining the samples of three decking products made from *P. radiata* treated using CCA, acetic anhydride, and steam, together with the information cards for each, the interview respondents were asked to rate the overall acceptability of each product. A Likert-like scale was used where 1 indicated highly acceptable and 5 highly unacceptable. The respondents were subsequently asked to rate the acceptability of each product across each of the 17 selection criteria previously considered, using the information card for that product as a reference. The purpose of this was not to do market research on these specific products, but rather to explore the rationale for the responses to different types and amounts of chemical modification.

Overall, acetylated pine was deemed to be most acceptable decking product of the three (mean=1.86), even though the information sheet supplied asked the respondents to consider it as being hypothetically twice the price of CCA-treated decking. Similarly, thermally treated pine was the next most acceptable treatment (mean=2.39), even though the respondents were asked to consider it as having half the life-expectancy of CCA-treated pine decking. This treatment was appealing on the basis of low chemical treatment and aesthetics. CCA-treated pine was ranked third overall (mean=3.04) in terms of acceptability. Note that acceptability is not the same as willingness to consider purchasing the product. A high price or lack of performance may limit willingness to purchase even where a product is seen as far more acceptable than an available alternative.

Looking at the responses of the different stakeholders, there is a clear disparity between the scientists and business people and the other groups (Table 1). While the scientists and business people perceived acetylated pine to be the more acceptable product considered, they preferred the CCA treatment over thermal treatment, whereas all of the other groups (especially the architects and consumers) ranked CCA treatment lowest. Analysis of the data about the acceptability of the products across the selection criteria revealed that the scientists and business people were placing a greater weighting on proven performance and trust in the manufacturers.

While a person may hold an academic preference for a particular product, this need not flow into their willingness to consider it for purchase or their consequent purchasing behaviour. In order to examine this, the respondents were asked to rate how willing they would be to consider purchase, given the hypothetical information on the three cards supplied. A rating of 1 indicated that they were definitely willing to consider purchase and 5 that they were definitely not willing.

The results revealed that there were a number of people who, even when unsure or uncertain about the acceptability of certain technologies (both the existing

TABLE 1–Acceptability of sample technologies by stakeholder group, where 1=highly acceptable and 5=highly unacceptable

Stakeholder group	Acceptability: Mean (s.d.)			Total (n)
	CCA-treated pine	Acetylated pine	Thermally treated pine	
Scientists	2.47 (1.17)	1.63 (0.96)	2.79 (1.18)	19
Business	2.36 (1.26)	2.08 (1.10)	2.64 (1.30)	14
Influencers	3.06 (1.30)	1.88 (0.86)	2.29 (1.26)	17
Selectors	3.47 (1.17)	1.95 (0.78)	2.53 (1.12)	19
Maori	3.00 (1.62)	2.07 (0.92)	2.36 (1.22)	14
Consumers	3.47 (1.07)	1.73 (0.58)	2.00 (1.02)	30
TOTAL	3.04 (1.30)	1.86 (0.84)	2.39 (1.17)	113

treatment and the hypothetical alternatives presented), were willing to consider purchase of that product. Overall, however, the distribution of preferences did not change. Acetylated pine decking was the preferred option, with scientists and business people placing CCA as their second choice and everyone else placing it third (Table 2).

TABLE 2–Willingness of stakeholder groups to consider purchase, where 1=definitely consider and 5=definitely not consider

Stakeholder group	Acceptability: Mean (s.d.)			Total (n)
	CCA-treated pine	Acetylated pine	Thermally treated pine	
Scientists	1.74 (1.24)	1.42 (0.96)	2.84 (1.21)	19
Business	2.20 (1.39)	1.93 (1.10)	2.47 (1.62)	15
Influencers	2.59 (1.58)	1.53 (0.62)	2.29 (1.26)	17
Selectors	3.26 (1.37)	1.68 (0.82)	2.58 (1.43)	19
Maori	2.64 (1.55)	1.71 (0.91)	2.36 (1.39)	14
Consumers	2.80 (1.37)	1.53 (0.73)	2.17 (1.05)	30
TOTAL	3.02 (1.47)	1.84 (0.85)	2.37 (1.31)	114

Discriminant function analysis and Hotelling's T^2 tests were used to determine if there were significant differences between the six sets of respondents and which selection criteria had the most important impact on this difference. A clear difference was found between the scientists, selectors, and consumers, with the influencers not exhibiting much difference to any other group (overlapping all of them). The Hotelling's T^2 tests between each pair of stakeholder groups revealed that scientists and selectors were not as concerned about price as consumers and Maori. Sustainably sourced raw materials were significantly more important to the selectors (architects) and scientists, while low waste in disposal was a greater concern for consumers and Maori. When comparing the scientists and selectors, it was found that the former were significantly more concerned about low waste in production, high durability, low maintenance costs, and trust in manufacturers. In contrast, the selectors (architects) interviewed were significantly more concerned about low chemical input in production and low emission of gases from newly manufactured wood products.

Thresholds of Acceptability

A distinction has been noted between primary parameters of acceptability (in-service performance) and secondary parameters (manufacture and disposal issues). Chemical input and emissions were of greatest concern in so far as they impacted upon the more important selection criteria of durability, strength, initial cost, maintenance costs, and family health and safety. This deduction was reinforced by the results of two open questions presented specifically to the professional stakeholders (n=70). The questions were teasers, asking them how much was too much and too little in terms of chemicals in wood. The researchers realised that acceptability was not a matter of chemical quantity, but the wording stimulated them to explain what the respondents saw the actual thresholds of acceptability to be.

When it came to describing the lower limits of acceptability for the chemical modification of decking products, the bottom line was without doubt the physical performance of the product. If there was not enough modification to ensure that the product was strong enough, long lasting enough, and would not fail, then it was deemed to be unsatisfactory. Forty-five (64%) of the professional respondents stated that the product being physically fit for purpose was the bottom line, while 10 (14%) also stated that this included avoiding potential adverse impacts on human safety caused by product failure. The next most important issues were meeting institutional requirements such as standards and codes (7%), maintaining market share (4%), and the type of chemicals used (4%).

With regard to defining the upper threshold of acceptability for chemical modification, 30 (43%) of the professional respondents referred to adverse impacts on human health and safety, and 28 (40%) mentioned harm to the environment. In many cases it was the same people identifying both of these criteria, the common theme being concern about toxicity, during manufacture, service, or disposal. Other major concerns were the impact of the chemicals on price and market share (19%), physical performance (7%), and failing to meet institutional requirements (7%). Two respondents were opposed to any chemical modification whatsoever.

In summary, so long as the price is right, the lower limit of acceptability was stated as the ability of the product to perform to expectation (equal to or greater than alternatives), while the upper limit was the perception of potential harm to humans or the environment (relative to alternatives). The open responses did not indicate the thresholds for deciding when a product was seen to be too expensive, too harmful, or unfit for purpose, but it is assumed that this will vary according to the individuals, their expectations, and the benchmarks available for comparison.

In order to assess how the three products assessed matched up to respondent expectations, all of the respondents (n=114) were asked to rate the acceptability of each product across the 17 important selection criteria identified by the focus groups. Again, a Likert-like scale was used. The aggregate results were then tabulated against the respondents' rating of the importance of these 17 selection criteria (Table 3).

The extent of linear relationship between the selection criteria was tested using Pearsons bivariate correlation (Table 4). This revealed fairly high levels of correlation between the following criteria: "sustainably sourced raw material"

TABLE 3–Acceptability of products according to selection criteria (n=114), where 1=highly acceptable and 5=highly unacceptable; the highest acceptability in each criterion is highlighted

Selection criteria	Importance: Mean (s.d.)	Acceptability: Mean (s.d.)		
		CCA	Acetyl	Thermal
Durable	1.32 (0.48)	1.84 (0.89)	1.55 (0.67)	2.64 (1.23)
Family health and safety	1.38 (0.71)	2.83 (1.41)	1.77 (0.78)	1.68 (0.92)
No warp, twist, and bow	1.48 (0.54)	2.51 (1.15)	1.58 (0.61)	2.02 (0.78)
Adequate stiffness and strength	1.53 (0.60)	2.10 (0.90)	1.71 (0.65)	2.11 (0.87)
Low maintenance costs	1.68 (0.68)	2.15 (0.88)	1.99 (0.79)	2.85 (1.07)
Proven technology	1.89 (0.95)	2.04 (0.94)	2.66 (1.02)	2.77 (1.06)
Desirable appearance	1.95 (0.82)	2.59 (1.01)	1.74 (0.76)	2.05 (0.84)
Low cost	2.06 (0.87)	1.93 (0.75)	2.72 (1.03)	2.45 (0.85)
Sustainably sourced raw material	2.09 (0.92)	2.11 (0.94)	1.82 (0.81)	1.67 (0.76)
Trust in the manufacturer	2.14 (0.99)	2.33 (0.99)	2.55 (0.94)	2.65 (1.03)
Minimal waste created in disposal	2.21 (0.97)	3.35 (1.32)	1.92 (0.86)	1.65 (0.73)
Recyclable	2.30 (1.00)	3.47 (1.28)	1.90 (0.82)	1.74 (0.81)
Low chemical input in production	2.32 (0.97)	3.20 (1.32)	2.27 (0.92)	1.68 (0.83)
Minimal waste created in production	2.37 (0.97)	2.85 (1.06)	2.27 (0.85)	1.97 (0.86)
Natural	2.38 (0.91)	2.89 (1.12)	1.86 (0.79)	1.78 (0.73)
Low emissions after manufacture	2.49 (1.02)	2.77 (1.29)	2.38 (1.00)	1.95 (0.91)
Low energy input in production	2.53 (0.92)	2.71 (0.91)	2.58 (0.89)	2.85 (1.03)

and "minimal waste created in production" (0.64); "naturalness" and "low energy input in production" (0.63); "low chemical input in production" and "low energy input in production" (0.63); "low chemical input in production" and "minimal waste created in disposal" (0.63); "low chemical input in production" and "low emissions from newly manufactured wood" (0.62); "recyclable" and "minimal waste created in disposal" (0.61); "minimal waste created in production" and "minimal waste created in disposal" (0.59); "low chemical input in production" and "minimal waste created in production" (0.58); and "proven technology" and "trust in the manufacturer" (0.53).

From the data we were able to derive a quadrant diagram comparing the products in relation to the respondents' non-standardised self-assessment of acceptable performance, price, and toxicity. For the purposes of interpretation, it was subsequently deemed appropriate to invert the Likert-like scale we used, so that 1=highly unacceptable and 5=highly acceptable. This produced a table where the upper right quadrant (Table 5) showed star performers, being highly acceptable on the most important selection criteria, while the lower right quadrant was essentially the zone of product disqualification, being highly unacceptable on the most important selection criteria.

The quadrant diagram produced from our data revealed that CCA-treated pine and acetylated pine were both seen as performing well according to the more important

TABLE 4–Pearson bivariate correlation coefficients between the 17 selection criteria

	Durable	Health	Stability	Maintenance	Proven	Appearance	Cost	Sustainable	Trust	Disposal	Recycling	Chemical	Waste	Natural	Emissions	Energy
Durable		0.04	0.35	0.14	0.22	0.28	-0.11	0.10	0.21	0.12	0.17	-0.12	0.06	0.01	0.03	-0.07
Health	0.04		0.09	0.22	0.07	0.07	0.15	0.21	0.23	0.43	0.20	0.35	0.36	0.34	0.38	0.29
Stability	0.35	0.09		0.12	0.19	0.40	-0.06	0.06	0.17	0.16	0.03	0.05	0.11	0.18	0.15	0.00
Maintenance	0.14	0.22	0.12		0.01	-0.05	0.29	-0.14	0.28	-0.01	0.01	-0.08	0.00	0.00	0.04	-0.01
Proven	0.22	0.07	0.19	0.01		0.22	-0.05	0.34	0.53	0.12	0.13	0.24	0.41	0.23	0.32	0.37
Appearance	0.28	0.07	0.40	-0.05	0.22		-0.24	0.12	0.23	0.08	0.08	-0.01	0.07	0.26	0.04	-0.01
Cost	-0.11	0.15	-0.06	0.29	-0.05	-0.24		-0.27	-0.04	0.10	0.00	-0.03	0.09	0.00	0.07	0.04
Sustainable	0.10	0.21	0.06	-0.14	0.34	0.12	-0.27		0.12	0.44	0.43	0.43	0.64	0.24	0.29	0.48
Trust	0.21	0.23	0.17	0.28	0.53	0.23	-0.04	0.12		0.09	0.09	0.26	0.30	0.17	0.26	0.29
Disposal	0.12	0.43	0.16	-0.01	0.12	0.08	0.10	0.44	0.09		0.61	0.63	0.59	0.41	0.62	0.36
Recycling	0.17	0.20	0.03	0.01	0.13	0.08	0.00	0.43	0.09	0.61		0.42	0.39	0.31	0.43	0.22
Chemical	-0.12	0.35	0.05	-0.08	0.24	-0.01	0.09	0.43	0.26	0.63	0.42		0.58	0.42	0.53	0.63
Waste	0.06	0.36	0.11	0.00	0.41	0.07	0.00	0.64	0.30	0.59	0.39	0.58		0.33	0.50	0.63
Natural	0.01	0.34	0.18	0.00	0.23	0.26	-0.03	0.24	0.17	0.41	0.31	0.42	0.33		0.47	0.28
Emissions	0.03	0.38	0.15	0.04	0.32	0.04	0.07	0.29	0.26	0.62	0.43	0.53	0.50	0.47		0.35
Energy	-0.07	0.29	0.00	-0.01	0.37	-0.01	0.04	0.48	0.29	0.35	0.22	0.63	0.63	0.28	0.35	

TABLE 5–Quadrant diagram: acceptability of products (mean) against important selection criteria (mean ratings), where 1=highly unacceptable and 5=highly acceptable

	Important selection criteria (mean ratings 3.0 to 4.0)	Very important selection criteria (mean ratings 4.0 to 5.0)
Product acceptable (mean ratings 3.0 to 5.0)	**Contenders** Important Acceptable	**Stars** Very important Acceptable
Product unacceptable (mean ratings 1.0 to 3.0)	**Unlikely** Important Unacceptable	**Disqualified** Very important Unacceptable

physical performance criteria such as durability and stability. The acetylated pine was deemed to be more acceptable than CCA-treated pine on many physical parameters (including strength and appearance), as well as potential health and safety, but less acceptable in relation to price. The thermally treated pine was seen to be more acceptable than both acetylated and CCA-treated pine across criteria such as health and safety, appearance, naturalness, low chemical treatment, and disposal issues. Despite this, it failed to deliver the same degree of physical performance as the other two products, and was consequently relegated to second or third place in the eyes of the respondents. In contrast, CCA-treated pine was seen as low cost, proven, and trusted, but a number of respondents deemed it unacceptable with regard to health and safety. This perceived failing placed this particular technology within the zone of disqualification for them, despite any benefits it may have.

One use of a quadrant diagram such as this is that it helps clarify why certain technologies are being seen as unacceptable or are not being considered for purchase. It also allows new technologies and product scenarios to be evaluated across a range of variables. Furthermore, differences in self-assessment by various stakeholder groups may be compared and contrasted. Diagrams could be derived from the data for each of the stakeholder groups, allowing a visual comparison and communication of differences in perception and reaction. A major question remains, however, as to why the stakeholder groups are reacting to the technologies in different ways. One aspect may be variation in weighting given to the tangible attributes of the product, but what other factors impact upon stakeholder attitudes?

Perceptual Differences

In examining the differences between the overall acceptability of the three decking products proposed and the respondents' willingness to consider purchasing them, major divergences were noted. The respondents could be categorised into three distinct groups on the basis of their reaction to the base technology (Table 6). One group, who could be called the Traditionalists (n=51, 46%), rated CCA-treated pine

TABLE 6–Categorisation of respondents by reaction to CCA-treated pine decking

		Acceptability of CCA-treated pine decking					n
		Highly acceptable	Acceptable	Unsure	Unacceptable	Highly unacceptable	
Consider purchase	Definitely consider	10	25	1	3		39
	Possibly consider	1	13	5	7		26
	Unsure		2	2	6		10
	Possibly not consider			2	15	6	23
	Definitely not consider			1	4	10	15
	n	11	40	11	35	16	113

as acceptable or highly acceptable and were willing or definitely willing to consider its purchase. A second group, the Objectors (n=38, 33%), rated CCA-treated pine as unacceptable or highly unacceptable and were unwilling or definitely unwilling to consider purchase. The third group, the Pragmatists (n=24, 21%), deemed CCA-treated pine to be unacceptable or were uncertain about its acceptability, yet they felt they would consider purchase or at least not rule it out as an option.

Discriminant function analysis and Hotelling's T^2 tests were used to determine the variables differentiating the three groups and their degree of separation. The groups displayed no statistically significant differences when it came to their appraisal of the importance of the 17 selection criteria; however, different criteria were used to score the three treatment types. Overall, Traditionalists tended to place greater importance on the strength and durability of the product. Objectors placed greater importance on low warp, twist, and bow, low chemical treatment and being recyclable. Pragmatists placed greater emphasis on low cost and low energy in production.

In order to further investigate the relative importance of certain selection criteria, the respondents were shown 10 cards. Each card listed one pairing of the following five criteria: selecting a low-cost product; selecting a high-performance product; selecting a familiar product; selecting a product with a low level of chemical treatment; and selecting a product with minimal emission of gases from newly manufactured wood. Respondents were asked to state which one of each pair was more important to them when choosing an appropriate decking material, thereby forcing a choice. High performance proved to be the most important criterion overall, being selected by more than 70% of respondents when placed against each of the other criteria. Minimal chemical treatment was next most important, followed by familiarity, low cost, and finally minimal chemical emissions.

In examining the forced choice findings, it was found that Traditionalists placed more importance on familiarity and high performance. Objectors placed more emphasis on minimal chemical emissions and treatment. Traditionalists and

Objectors differed from Pragmatists by placing more emphasis on high performance than on low cost. The differences between the groupings were not statistically significant but were marked.

The business people and scientists surveyed were predominantly Traditionalists (79% and 68% respectively) (Table 7). In contrast, the selectors (architects) were predominantly Objectors (53%) or Pragmatists (21%), finding CCA unacceptable or being uncertain about it. The consumers and influencers were also largely Objectors (37% and 35% respectively) or Pragmatists (38% and 24% respectively). We were very interested in finding out why there was such a vast difference in the reactions of these stakeholder groups to the base technology.

TABLE 7–Distribution of reactions to the base technology by stakeholder group

Stakeholder group	Traditionalists (%)	Pragmatists (%)	Objectors (%)	Total (n)
Scientists	68	16	16	19
Business	79	0	21	14
Influencers	41	24	35	17
Selectors	26	21	53	19
Maori	50	14	36	14
Consumers	27	37	37	30
TOTAL	46	20	34	113

With regard to the intrinsic and extrinsic properties of the decking products, statistical analysis of the questionnaire data revealed a clear difference between the scientists, selectors, and consumers, while the influencers were a rather broad group that did not exhibit much difference from any other group. Scientists and architects proved to be not as concerned as the end-users about the price of the product, possibly due to being further removed from the purchasing decision. The scientists and selectors gave much greater weighting to selecting sustainably sourced raw materials than the end users did, while the consumers and Maori were more concerned about low waste in disposal than the scientists and selectors. With regard to differences between the scientists and architects, the former considered low warping, high durability, low waste in production, trust in the manufacturer, and low maintenance costs to be more important, whereas the architects felt minimal chemical input and emissions were more important.

Given the notable variation in representation of Traditionalists and non-Traditionalists between the various stakeholder groups, two workshops were subsequently held. The purpose of these workshops was to explore the capacity for dialogue and understanding between divergent stakeholders. One workshop had five scientists and five architects in attendance. The second workshop had five business people and five influencers. Stakeholder representatives were selected on the basis of professional interest plus known ability to relate well in workshops.

In the workshops, the representatives of the two stakeholder groups were presented with the findings of the research to date, including the life cycle assessment data for the three products and the divergences in reactions from the respondents in the different groups. Separating the two groups, each was asked to consider why they felt that the respondents from their industry may have responded the way that they did. They were also asked to consider why the other stakeholder group may have had such a different reaction to the base technology. The two groups were then brought together again to report on their discussion, thus obtaining some insight into (a) the mindset of the other group and (b) the perception of the other group as to their own mindset. Such feedback provided a number of insights for both researchers and participants.

When the results of each break-out session were reported back by the spokesperson from each stakeholder group, several key comments were noted by them as clarifying their group's position. The business representatives stated that the business respondents were probably largely Traditionalist given that they were immersed in the present market environment, lacking much opportunity to look into the future regarding new technologies. Their primary concern was to avoid short- to medium-term problems by selecting proven and familiar products. New technologies would be considered only if the existing technology was proven to be excessively harmful or new products had been proven to have improved performance. In contrast, the scientists stated that the producer respondents were probably Traditionalist given that they had confidence in their community to come up with solutions in the future, either through reducing any problems associated with disposing of CCA-treated pine or in developing an alternative product. Given this faith in future scientific improvements, they saw no need to change from a product which they believed to be proven, familiar, and of lower risk than new technologies still in development.

The architects considered that the selector respondents had been largely non-Traditionalist given that their goal was not the mere creation of a structure but a healthy living environment. As such, they were willing to consider novel new technologies which could improve on the quality of the living environment in the medium term. In contrast, the influencers stated that they were largely non-Traditionalist given that they were watching overseas developments with an eye to ensuring market access and avoiding disposal problems and/or potential litigation problems in the longer term.

Each of the responses noted in the workshops reflected the different operating rationale and experiences of the stakeholder group, and each was a valid risk-management strategy. In order to test whether or not these insights about different operating rationales held true beyond just these particular workshop participants, a small phone survey of architects (n=9), business people (n=8), regulators (n=12), and scientists (n=18) was undertaken in March 2007. The respondents were asked which one of four statements best reflects what most of their group were seeking to provide to consumers. The findings provided a degree of validation for the workshop results: 56% of the architects chose "we seek to provide quality living environments", 50% of the business people chose "we seek to provide trusted products", 58% of the regulators chose "we seek to promote safer living environments", and 56% of the scientists chose "we seek to improve products". The remainder of the responses in each group were divided across either two or three of the alternative statements, reflecting individual agendas within each group.

The varying rationales of these four stakeholder groups could be represented in a quadrant table where architects and business people looked to the short to medium term and scientists and influencers were looking to the long term; however, architects and scientists were seeking to improve the living environment or product, while the business people and influencers were seeking to maintain sales and avoid problems (Table 8). In other words, the primary factors distinguishing the risk management of the four professional focus groups were the temporal focus (present or future) and the litigation focus (improving the product or avoiding problems). The conjunction of these factors altered the degree of emphasis that the respondents placed on proven and trusted products with existing chemical regimes, as opposed to moving to new products with different amounts or types of chemical modification. Familiar products with a proven high performance accorded with the mindset of the business people and scientists, while products with what was perceived to be a safer chemical treatment were given greater consideration by the architects and influencers.

Given that members of each respondent group were immersed in their own rationale, they naturally had difficulty seeing how and why other groups were reacting differently to the same technologies and related information. For each of

TABLE 8–Deduction of differing risk-management strategies among four stakeholder groups

	Present focus	Future focus
Improvement focus	**Architects** 74% non-Traditionalists Look to new, potentially more benign products, to improve health of living environment	**Scientists** 68% Traditionalists Promote what is tried and true, with faith in improving technologies or improving disposal
Avoiding problems	**Business** 79% Traditionalists Promote what is tried and true, seeking to maintain present sales and avoid problems	**Influencers** 59% non-Traditionalists Look to new, potentially more benign products, to maintain market access and avoid problems

the four stakeholder groups, their priorities determined that theirs was the most appropriate and valid way of assessing the technology. Each had an operating rationale and risk-management strategy that was valid, although each was derived from different approaches and ended with different perceptual responses. Such are the perceptual realities when considering the acceptability of technologies, whether new or existing.

Application

The methodology used in this study was found to be a useful tool for the appraisal of new technologies, identifying the relative importance of criteria affecting both preference for products and reasons for disqualification, as well as helping define reasons for differences in the responses of various stakeholder groups. The quadrant diagram and workshops provided an excellent tool for helping both the researchers and different groups to appraise the benefits and problems with different products, as well as to gain insight into why each group was reacting differently. Such insight is useful in evaluating the acceptability of new or existing technologies, pre-empting conflicts, ascertaining information gaps, clarifying reasons for miscommunication, and developing appropriate communication strategies.

Overall, the research produced a proactive process for analysing stakeholder concerns and communication needs concerning technology development (Fig. 1).

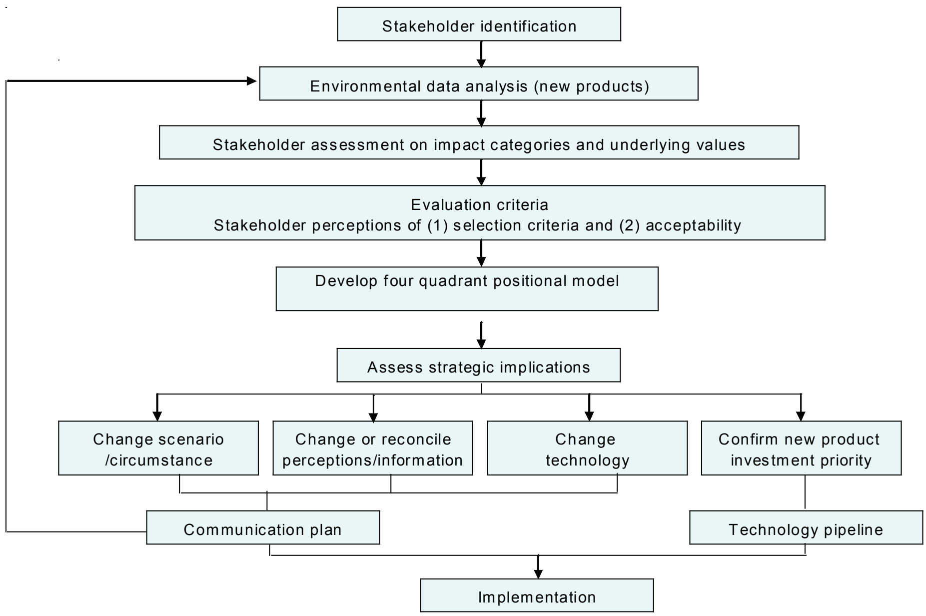

FIG. 1–Process map for stakeholder analysis of new technologies

This process actively engages stakeholders rather than relying solely on expert assessment; it also facilitates mutual understanding of concerns which could arise from any part of the wider life cycle of the product over and above its immediate physical properties and function. This process can be employed using scenarios and iteration in order to gauge potential impacts and conflicts prior to investment in development or market introduction.

The introduction of the life cycle assessment data at the workshops was found to alter the perceptions of a couple of the stakeholder representatives present. As a consequence, it would have been beneficial either to have had the life cycle assessment data prior to the perceptual research, or to have been able to have completed a second iteration of the survey with the life cycle assessment data. These options were not possible in this instance due to time constraints. Having clarified the categories of important variables (physical performance, cost, proven ability, health and safety, and environmental impact), it may also have been beneficial to have used a conjoint value analysis using either paired comparisons or a card sort approach for a more discrete number of selection criteria.

CONCLUSIONS

The criteria for accepting or rejecting a technology may be something quite different from the performance or cost of the finished product. In considering stakeholder reactions to the different types and amounts of chemical modification in the production of three pine decking products, it was found that acceptability was conditioned by:

(1) Intrinsic properties: what the product itself can provide in the way of relative physical performance, price, and health and safety;

(2) Extrinsic properties: the history of the product and trust in manufacturers or suppliers;

(3) Risk management: the operating rationale and experiences of the stakeholder group.

In terms of the intrinsic properties, fitness for purpose was deemed to be most important, price was a close second, while issues relating to manufacture and disposal were tertiary. That is, while deemed to be somewhat important, they were not at the forefront of people's minds when they were selecting decking products. It is uncertain, however, to what extent respondents reduced the weighting they would give to price and increased the weighting given to health and safety, given the topic of the study.

A quadrant diagram produced from the stakeholders' assessments of the importance of selection criteria and the acceptability of the three products being evaluated allowed identification of problematic attributes, as well as providing an assessment of areas of advantage and weakness for new technologies. Such a diagram allows easy communication and appraisal of reactions to different technologies based on actual or hypothetical information presented to them. The graphical display of such data helps stakeholders to see what is important in the products, and why people are strongly approving or objecting to the products.

In providing displays for different stakeholder groups, it was possible to note variations in reactions. The displays, however, only reflect the ratings of the intrinsic and extrinsic properties, all of which will be influenced by the operating rationale and experiences of the different stakeholder groups as well. An understanding of how and why the different groups are responding as they are also needs to be developed in order to avoid groups talking at cross-purposes. In this study it was deduced that the primary factors distinguishing the risk management of the four professional focus groups were the temporal focus (present or future) and the litigation focus (improving the product or avoiding problems). The conjunction of these factors altered the degree of emphasis that different stakeholders placed on proven and trusted products with existing chemical regimes as opposed to moving to new products with different amounts or types of chemical modification. The scientists surveyed, for example, gave the response of endorsing the base technology given their faith in improving the existing product sometime in the future. Dialogue on the impacts of new technologies may be improved through the identification of such risk-management strategies.

There are future research opportunities in looking at the contribution of life-cycle assessment data to improve understanding of the intrinsic properties of the products, as well as applying the research process to another set of products in order to substantiate its utility and application to other bio-based sectors.

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Appendix 1

STANDARDISED HYPOTHETICAL DESCRIPTIONS OF THE CASE STUDY TECHNOLOGIES

CCA-treated Pine

CCA-treated pine is sourced from sustainably managed plantation forests. The wood is pressure-treated with Copper Chrome Arsenate solution, which is fixed into the wood.

This chemical treatment enables the wood to be used outside without protection for purposes such as decking. While untreated pine will last for only about 5 years, a treated pine deck will last at least 25 years before it starts to decay sufficiently to be considered unsafe.

Although the CCA solution is fixed into the wood, a very small quantity of arsenic will leach from the wood over time. The treated pine is also difficult to dispose of at the end of its productive life. Burning the wood produces arsene gas, but burying the wood in landfills can cause environmental problems due to leaching of chemicals. For these reasons, CCA-treated pine has been banned or phased out of some domestic uses, including decking, in the United States and Europe. Nevertheless, CCA-treated pine is still used extensively in New Zealand.

Acetylated Pine

Acetylated pine is manufactured from timber from sustainably managed plantation-grown pine. It is kiln-dried and then treated with a chemical known as acetic anhydride. Although this chemical is an irritant and can be highly flammable, it changes during processing. The result is a wood product which is not toxic, together with a solution of acetic acid (otherwise known as vinegar) which can be re-used. The wood consequently smells like vinegar. Essentially, it is pickled.

At the end of its productive life the waste wood can be safely burned or disposed of, being non-toxic. As with any kiln-dried timber product, however, heating and drying during manufacture cause volatile chemicals (such as formaldehyde) to evaporate from the wood in small quantities for a limited period of time.

Given that the wood is kiln-dried in addition to being treated, the product is more expensive than CCA-treated pine. However, acetylated pine is more stable than treated pine in terms of warping or twisting, being heavier and harder. Decking made from acetylated pine is expected to have a life of about 30 years. It does not change colour with age and is easy to maintain. It is easy to paint and stain, and does not crack or splinter.

Thermally Treated Pine

Thermally treated pine is made from timber harvested from sustainably managed plantation pine, which has been heated through with steam to very high temperatures. There is no chemical addition to the wood. Instead, the wood has essentially been cooked through.

At the end of its productive life (it lasts about 10–15 years as decking) the waste timber can be safely burned or disposed of, being non-toxic. Although there is no chemical treatment of the wood, heating and drying during manufacture cause volatile chemicals (such as formaldehyde) to evaporate from the material in small quantities for a limited period of time.

Given the energy used in manufacture, the final product is more expensive than CCA-treated pine, though not as expensive as acetylated pine.

Thermally treated pine has been used in Scandinavia for decking and has proved to be more durable than untreated pine, but not as durable as CCA-treated pine. It is light but stable (not twisting, warping, or bowing) and will not move as much as treated pine. It has the same gluing, nailing, and painting properties as both untreated and treated pine, but it could be more prone to cracking, checking, and splintering. The colour of the wood also silvers over a period of time if exposed to sunlight.