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is likely to be long-term but would enable incremental progress towards a target.

Assuming other production costs remain unchanged, the relative economic advantages from changing various wool characteristics are indicated by their relative economic values (Table 1). These are however, likely to be underestimated for future enterprises supplying wool for specific manufacturing purposes. While a reduction in mean fibre diameter has the potential to provide the greatest relative return, genomic technologies in the longer term will provide the means for step changes in all economically important fibre attributes. However, many of the characteristics important in processing are related to on-farm management issues. Regardless of the type of wool produced on a farm it is imperative that the sheep be managed and the clip prepared in the best way possible to maximise the advantages present as a result of any changes induced by genomic technologies.

CONCLUSION

Manipulating fleece cover over the body of sheep and thereby reducing shearing and husbandry costs will support all farmers by making sheep farming easier and addressing animal welfare

issues that are likely to become more pressing in the future.

It is clearly evident that small changes in individual fleece characteristics will have a limited effect on individual sheep farmer's returns unless they can continue to exploit the differences between their clip and the national clip through the establishment of special relationships with individual processors. However, price premiums are likely to decline with time as previous examples in this industry have illustrated.

As a result of current investment in wool genomics in Australasia, opportunities will be created for additional novel uses for wool, to enable the sheep and wool industries to continue to remain viable businesses in future. The application of such research will support wool production for both niche and commodity markets. Niche opportunities are characterised by low volume, higher value wool but the markets are likely to be more fickle and demanding. Commodity production will continue to absorb the majority of the wool clip for the foreseeable future. These markets are characterised by a high volumes of lower value wool but still present opportunities for more consistent wool types better fitted for specific purposes.

Concluding remarks: Genomics and the future of wool production

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Wool is a natural product from renewable, living systems - grass, microbes and sheep. Several papers in this session have pointed out the consequent high variability and competitive disadvantage of wool in relation to synthetic textiles. Yet the biological basis of wool production now presents an opportunity to capitalise on the huge worldwide development of gene technologies and genetic information for the benefit of sheep farmers.

The preceding technical papers represent feats of gene sequencing, expression analysis, bioinformatics, gene mapping, and functional genomics that themselves depend on a much greater, global enterprise covering many fields of biological science. Each one of the tens of thousands of expressed sequences isolated from wool follicles is being compared with public gene databases, including the human genome. These are the first steps toward identifying the sets of genes that determine fibre characteristics (Yu *et al.*,

2006; Plowman *et al.*, 2006) and fleece distribution (Scobie *et al.*, 2006). The major challenge ahead will be to apply this new knowledge in practical, economically feasible solutions to meet industry needs.

So what might the farming technology of the future look like? Discoveries in sheep genomics can be applied by one of three possible routes; tools for genetic selection, therapeutics, or development of transgenic livestock.

Selection markers can make possible more rapid genetic improvement based on pre-existing variation within flocks. Markers are especially useful for difficult to measure or late developing traits. For example, Scobie *et al.* (2006) showed fleece cover phenotypes of "easy-care" and other sheep do not develop until after one year of age. Although there are currently no commercial markers available for wool traits, Abbott *et al.* (2006) point to several interesting candidates, especially amongst keratin genes, which could be

of future use to ram breeders. More powerful genome scanning has been hampered in sheep by a paucity of single nucleotide polymorphisms (SNPs) and microsatellite markers, and of mapping flocks with relevance to wool phenotypes. This limitation is now being overcome with the generation of large sets of SNPs and the establishment of the Falkiner mapping flock (Forage & Hynd, 2006).

The therapeutic approach generally requires a lengthy development phase after the discovery of biochemical, physiological or genetic mechanisms that are amenable to pharmaceutical manipulation. An existing commercialised example is the biological defleecing system using epidermal growth factor. A more ambitious target is altering fleece development *in utero* (Forage & Hynd, 2006) which could enable rapid responses to changing market signals. The use of hormones or mimetics also has the potential to reduce variation in fibre characteristics induced by seasonal and reproduction effects (Kendall *et al.* (2006).

Pioneering sheep transgenics programmes on both sides of the Tasman have demonstrated that this technology can alter wool growth rate and wool characteristics (Powell *et al.*, 1994; Damak *et al.*, 1996). This approach is not considered socially acceptable at present, and has been specifically ruled out by both Meat & Wool New Zealand and SheepGenomics in Australia. Nevertheless, attitudes might change and, with increasing understanding of functional genomics, genetic modification would allow many innovations that are not otherwise possible. Applications that have been considered are; novel keratin compositions, cysteine biosynthesis, pest resistance and complete removal of pigmented fibres. Advances in understanding the genetic control of wool keratin composition (Plowman *et al.*, 2006) would provide a foundation for targeted transgenic modifications should application of the technology become acceptable in the future.

All genomics projects require a continuous long-term commitment. Significant Australian industry investment is now aimed at reducing fibre diameter, increasing fleeceweight, developing new

harvesting methods and finding a replacement for the mulesing procedure (Forage & Hynd, 2006). These are all issues from which New Zealand sheep farmers can benefit directly, although they also face issues relating to seasonality of production, and managing the effects of a different suite of diseases and mycotoxins. It is thus important for New Zealand farmers to be able to reap the benefits by leveraging New Zealand, Australian and international research efforts. Quantum changes through gene-based innovations have the potential to permanently change the industry in the same way that mechanical technologies of refrigeration and shearing affected the course of New Zealand sheep farming after their introduction in the 1880s.

Successful development and adoption of new technologies require integration across the industry (McDermott *et al.*, 2006). It is crucial that improvements made by growers are not traded away in the existing high volume, low profit-margin industry structure (Sumner & Davison, 2006). More direct relationships using less variable, more closely specified fibre are required to establish differentiated products in multiple niche markets. Diverse, high value markets have already been developed for solubilised keratin, and determination of fibre composition promises to become a basis for further product specification (Plowman *et al.*, 2006).

There will be large challenges ahead in harnessing genomic technologies in the service of the New Zealand wool industry. However the opportunities that these technologies afford could be crucial to the future viability of the industry. Success will require a shared appreciation of the task, long-term commitment, and good communication throughout the wool industry and with research providers and funders. The common goals will be greater efficiency of production, uniformity of product and, most importantly, the creation of new end-uses for wool which increase the demand for wool products with unique properties in the international market place.

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