Institution: WestCHEM

Unit of Assessment: Sub-panel 8 – Chemistry

Title of case study: Listen to the trees: Improving the timber supply chain in the UK

1. Summary of the impact

The forestry and timber-processing sector contributes about £2,000M per year to the UK economy. There are significant benefits to be gained by converting the maximum possible percentage of UK wood into construction timber products because the highest returns in terms of price and environmental impact are achieved with construction grade timber. WestCHEM research has contributed to the development of acoustic tools that allow construction-grade timber to be identified in the forest. This research also led to changes in UK Forestry Commission planting policy, with 'improved' stock now accounting for >80% of new planting across both public and private sectors, yielding an estimated increase of £75M in the market value of these trees.

2. Underpinning research

Context

Most of the underpinning research and its transformation into impact were carried out within the Strategic Integrated Research in Timber (SIRT) project, a collaboration between the Forestry Commission, Edinburgh Napier University, and the University of Glasgow (WestCHEM), initiated by a Scottish Funding Council strategic grant (2003-2007) and continuing to the present with funding from industry, RCUK, and the European Commission. The aims of the SIRT Project are to understand wood structure and its relationship with timber performance, and to promote the use of UK-grown Sitka spruce in the construction industry. SIRT spans from molecules to trees and from the forest to the building site. WestCHEM's contribution stems from previous BBSRC-funded research on cellulose structure (2000-2003) including novel spectroscopic and scattering methods to probe disorder and mechanical function.

Key Research Findings

Wood is a composite material based on cellulose fibres (microfibrils) embedded in a matrix of other carbohydrate polymers and lignin. WestCHEM research led to the determination of the structure of the cellulose microfibrils [1-3] and their interconnection through disordered interfaces with other wood polymers [3,4]. Under tension, wood can stretch by two mechanisms. One is by elastic stretching of the cellulose fibres themselves, when they are well aligned with the grain in the stiffest and strongest wood. The other is a time-dependent, slip-stick mechanism termed 'molecular Velcro' [4]. Using the metaphor of microfibrils as two pieces of Velcro and of hydrogen-bonded, non-cellulosic polymers as the hooks and loops between them, tensile force detaches the connections from the disordered microfibril surfaces [3], allowing the microfibrils to slide until the 'Velcro' re-attaches and restores the original strength of the structure [4].

The progressive transition between these two stretching mechanisms explains the steep and near-linear dependence of wood stiffness on cellulose orientation [5], a key element in the impact of the research on the genetic improvement of trees. Previously it had been thought that stiffness was controlled more by density, which decreases in fast growing trees. In 2004-2007 WestCHEM researchers collected a large body of x-ray data on microfibril orientation in Sitka spruce trees of varying genotype and showed that fast growing trees do not necessarily suffer the penalty in stiffness that had previously been assumed [6].

The other key development was the introduction of acoustic methods for measuring wood stiffness in standing trees. In principle, the stiffness of the wood is proportional to the square of the speed of a sound wave travelling between two probes attached at different heights on the side of the tree. However, the acoustic frequency is so high that part of the 'molecular Velcro' component is too slow to be captured. The standing-tree acoustic stiffness therefore differs from the bending stiffness measured by the standard machines used to grade commercial timber. In addition, the dominant path of the sound wave is just under the bark, where the cellulose is better oriented, and the wood is therefore stiffer than in the rest of the tree. Both problems led to scepticism about acoustic methods when these were first introduced. However, understanding how wood stretches encouraged the WestCHEM group to persist and find practical solutions. The ratio of acoustic to bending stiffness was quantified by laboratory-scale calibration on well-characterised material, and detailed measurements and modelling of the radial variation of microfibril orientation, density, and stiffness allowed the properties of timber sawn from any point within a tree to be predicted from measurements at its surface [6]. The WestCHEM researchers who carried out these experiments were members of the SIRT field teams that did the first successful standing-tree acoustic surveys in the UK [6].

Key Researchers

Dr Michael Jarvis (appointed 1979, now Reader) led a group that included Clemens Altaner (SIRT RF 2004-07); Shaun Mochan (visiting researcher on sabbatical from the Forestry Commission, 2007) and 5 PhD students funded or co-funded by the forestry industry (2004-2013).

3. References to the research

Key references to the research are [3] and [4], which are submitted in REF2 and [6] which describes the path to impact.

[1] M. Jarvis, Cellulose stacks up. *Nature* **426**, 611-612 (2003). (doi:10.1038/426611a)

[2] A.Šturcová, I. His, D.C. Apperley, J. Sugiyama & M.C. Jarvis. Structural details of crystalline cellulose from higher plants. *Biomacromolecules* **5**, 1333-1339 (2004). (doi: 10.1021/bm034517p)

[3] A.N. Fernandes, L.H. Thomas, C.M. Altaner, P. Callow, V.T. Forsyth, D.C. Apperley, C.J. Kennedy and M.C. Jarvis. Nanostructure of cellulose microfibrils in spruce wood. *Proceedings of the National Academy of Sciences of the USA,* **108**, E1195-E1203 (2011). (doi: 10.1073/pnas.1108942108)

[4] C. Altaner & M.C. Jarvis. Modelling polymer interactions of the 'molecular Velcro' type in wood under mechanical stress. *Journal of Theoretical Biology* **253**, 434-445 (2008). (doi: 10.1016/j.jtbi.2008.03.010)

[5] D.J. Cosgrove and M.C. Jarvis. Comparative structure and biomechanics of plant primary and secondary cell walls. *Frontiers in Plant Physiology* **3**, 204-209 (2012). (doi: 10.3389/fpls.2012.00204)

[6] J. Moore, B. Gardiner, D. Ridley-Ellis, M. Jarvis, S. Mochan, and E. MacDonald, Getting the most out of the United Kingdom's timber resource. *Scottish Forestry,* **63**, 3-8 (2009). (http://eprints.gla.ac.uk/38551/)

4. Details of the impact

Background

The forestry and timber processing sector as a whole contributes about £2,000M per year to the UK economy and supports about 40,000 jobs. Of the 2.5 million tonnes of UK timber harvested annually, approximately one-third is of suitable quality for transformation into construction-grade sawn products. The remainder is used for paper, chipboard, and biofuel, commanding a price about half that of timber for construction [1]. The carbon in these other products is returned to the atmosphere within 1-10 years, compared to 50-100 years for timber used to build houses [2]. Consequently, there are both financial and environmental reasons to channel the maximum possible percentage of UK timber into the construction industry. To satisfy the UK Building Regulations, timber has to meet the C16 quality specification. In practice the limiting C16 requirement for Sitka spruce, the prevalent conifer species in the UK, is its stiffness: hence the relevance of the WestCHEM research.

Path to impact

From the outset of the SIRT Project in 2004, its research and KE goals were planned together by a management board with majority industrial representation. KE was implemented through industry workshops and the Forestry Commission's simple but efficient system of Information Notes for forest managers. Since 2004, four Glasgow PhDs have been co-funded by the Forestry Commission and one part-time PhD student, a professional timber buyer, is fully funded by Egger Forestry Ltd.

Nature of the Impact

Acoustic tools for measuring timber quality in the forest

Acoustic technology based on the WestCHEM research described above and adapted for commercial use [Sources 3 and 4] was adopted in 2011 by James Jones Ltd for measuring stiffness in standing trees [Source 5]. James Jones Ltd is the second largest sawmilling company in the UK. Sawmillers purchase standing timber, which is then felled, transported, and processed prior to machine grading. Normally about 10% of sawn products fail to meet the C16 grading standard and must be diverted to pulping or biomass fuel [Source 3]. The costs (and embodied energy) of transporting, sawing, and kiln-drying these outgrades are then wasted, amounting to about £6M/year UK-wide [Sources 1and 6]. Selecting parcels of standing trees that will give a low outgrade percentage is a crucial skill of timber buyers. James Jones Ltd is now using acoustic measurements as a decision support tool alongside the traditional, empirical skills of their buyers [Source 5]. In these circumstances it is difficult to quantify the gain, but a realistic estimate is a 1% reduction in outgrades, leading to a saving of about £0.4M since the adoption of the technology.

A further advance in profitability would be possible if individual logs of high or low stiffness, rather than stands of trees, could be identified at felling and consigned directly to the sawmill or elsewhere. Acoustic devices attached to the harvesting machinery are under development by the spin-out company Timber Sonics, started up in 2011 by Shaun Mochan, a Forestry Commission researcher who was on sabbatical in WestCHEM in 2007.

Genetically improved Sitka spruce

Before the study of P. McLean under Jarvis's supervision, it was assumed that the stiffness of Sitka spruce wood was controlled mainly by density, and that fast growing tree genotypes would produce low-density timber of poor stiffness that would not meet the C16 specification for construction purposes. The WestCHEM research showed that, although low density is indeed connected with fast growth, stiffness need not be. Cellulose orientation is much more important than density in determining the stiffness of the wood [Source 7]. It is, therefore, possible to combine fast growth, straight stems (giving improved out-turn at the sawmill), and stiff timber (due to good cellulose orientation). These findings were disseminated informally to the forest industry in 2006-2007 [Source 8] and a Forestry Commission Information Note followed in 2008 [Source 9]. The private forestry sector has enthusiastically adopted improved planting stock and the large forestry company UPM Tilhill is planting improved material almost exclusively. Across both public and private sectors, improved stock now accounts for over 80% of new planting [Source 10] and around 50M improved trees have been planted since 2008. The change has been driven by the predicted increase in total wood volume as well as increased sawlog output, but it would have been inhibited if the perception that improved trees would fail to produce construction-grade timber had persisted [Source 10].

The economic benefits are difficult to estimate when trees take typically 40 years to mature and when there are uncertainties concerning the influence of the biomass energy market and the restructuring of UK forests. However, at harvest the improved trees planted between 2008 and 2013 are expected to yield 15M m^3 of additional sawlogs [Source 9], leading to an increase of £75M in the market value of these trees at harvest if calculated at today's prices [Source 1]. The increase in total yield at harvest is predicted to be 12M m^3 [Sources 9,10], equivalent to 7M tonnes of fixed CO_2, while about 8M tonnes of CO_2 equivalent will be locked up for the lifetime of the buildings incorporating the additional sawn timber [Source 2].

5. Sources to corroborate the impact

[1] Forestry Commission, 2012. Coniferous Standing Sales Price Index for Great Britain.

[2] Carbon Benefits of Timber in Construction. Forestry Commission Scotland, 2006.

[3] S. Mochan, J. Moore and J Connelly. Using acoustic tools in forestry and the wood supply chain. Forestry Commission Technical Note, 2009.

[4] B. Gardiner & J Moore. Implications for forecasting stiffness. Private Sector Production Forecasting Meeting, Edinburgh, 9 March 2009.

[5] Information from Harvesting and Operations Manager, James Jones and Sons Ltd, who is willing to be contacted for corroboration if required.

[6] Forestry Commission. Forestry Statistics 2013.

[7] J.P. McLean, R. Evans and J.R. Moore. Predicting the longitudinal modulus of elasticity of Sitka spruce from cellulose orientation and abundance. *Holzforschung* 64, 295-500 (2010). (doi: 10.1515/HF.2010.084)

[8] BBSRC Annual Report 2006-7 p.15.

[9] S. Mochan, S. Lee and B. Gardiner. Benefits of improved Sitka spruce: volume and quality of timber. Forestry Commission Research Note, 2008.

[10] S. Lee & G Watt. Choosing Sitka spruce planting stock. Forestry Commission Practice Note, 2012