# J. W. GOTTSTEIN MEMORIAL TRUST FUND

The National Educational Trust of the Australian Forest Products Industries



## LASER-INDUCED BREAKDOWN SPECTROSCOPY (LIBS): A NOVEL WOOD QUALITY EVALUATION TOOL

**SIMON POTTER** 

2006 GOTTSTEIN FELLOWSHIP REPORT

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## Joseph William Gottstein Memorial Trust Fund

The Joseph William Gottstein Memorial Trust Fund was established in 1971 as a national educational Trust for the benefit of Australia's forest products industries. The purpose of the fund is "to create opportunities for selected persons to acquire knowledge which will promote the interests of Australian industries which use forest products for the production of sawn timber, plywood, composite wood, pulp and paper and similar derived products."

Bill Gottstein was an outstanding forest products research scientist working with the Division of Forest Products of the Commonwealth Scientific Industrial Research Organization (CSIRO) when tragically he was killed in 1971 photographing a tree-felling operation in New Guinea. He was held in such high esteem by the industry that he had assisted for many years that substantial financial support to establish an Educational Trust Fund to perpetuate his name was promptly forthcoming.

The Trust's major forms of activity are:

- 1. Fellowships and Awards each year applications are invited from eligible candidates to submit a study programme in an area considered of benefit to the Australian forestry and forest industries. Study tours undertaken by Fellows have usually been to overseas countries but several have been within Australia. Fellows are obliged to submit reports on completion of their programme. These are then distributed to industry if appropriate. Skill Advancement Awards recognise the potential of persons working in the industry to improve their work skills and so advance their career prospects. It takes the form of a monetary grant.
- 2. Seminars the information gained by Fellows is often best disseminated by seminars as well as through the written reports.
- 3. Wood Science Courses at approximately two yearly intervals the Trust organises a week-long intensive course in wood science for executives and consultants in the Australian forest industries.

Further information may be obtained by writing to: The Secretary J.W. Gottstein Memorial Trust Fund Private Bag 10 Clayton South VIC 3169 Australia



Simon Potter is the deputy general manager of Ensis Wood Quality, a business group that helps industry understand, manage and get maximum value from variable wood and fibre resources.

The focus of Simon's research is rapid assessment techniques for wood qualities and nondestructive techniques to examine the best uses for wood. These are techniques that not only help processors segregate wood according to its most appropriate use but also inform breeders which wood to grow according to the processors' demands.

Simon has a PhD in molecular biology from the University of Edinburgh. He joined CSIRO in 2004 after working for seven years with the Pulp and Paper Research Institute of Canada (Paprican).

In 2005 he won the CSIRO Corporate Award for Business Excellence in recognition of his role in securing the sale of the SilviScan system to Cana da.

Simon is a member of the Technical Association of Pulp and Paper Industry in the United States (TAPPI) and the Poplar Genome Science Council.

One of Simon's latest projects is the establishment of a wood informatics centre - a facility that is unique in the world and one which he hopes will provide a holistic understanding of how wood is formed, its structure and how that structure affects its enduse.

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#### **Executive summary**

This report describes progress towards developing an optimised and validated laserinduced breakdown spectroscopy system for rapid, accurate and simultaneous inorganic elemental analysis of wood. Species-specific calibrations were developed for tree species relevant to the Australasian forest products industry (data currently confidential to ORNL). Further calibrations will elucidate contaminated timber (arsenic) in the wood waste stream diverted from landfill. Proof of concept work will demonstrate the innovative capacity of this technique to address wood quality impacts on wood suitability for engineered wood products.

Major findings of this study:

- Laser-induced breakdown spectroscopy (LIBS) has been assessed as a useful technology for application in the forest products industry.
- A working collaboration between Ensis and the Oak Ridge National Laboratory has been established in the LIBS development area.
- LIBS technology can be adapted to the detection and quantification of inorganic elements in radiata pine wood samples several potential industrial applications for the technology are proposed.
- Magnesium, aluminium, calcium, titanium, sodium and silica have been chosen as initial proof of concept targets and were detected in the samples provided.
- Initial experiments suggest that LIBS can be used to analyse the resin-wood interface in engineered composite products.

#### Introduction and background

Trees are biologically complex organisms, intrinsically variable in both morphology and chemistry [1]. The degree of this variability is a function of complex interactions between genetics and environment. The quality of wood – be it for the solid wood, panel or pulp and paper industries – is determined by the fundamental properties of the material itself and is therefore subject to the variability inherent in the raw material. Although both hardwoods and softwoods are composed of many different elements, all of which provide functions vital to tree growth, they are primarily comprised of lignin, cellulose and he micellulose. Trace elements, such as calcium – a component of plant cell walls – nitrogen, phosphorus, magnesium, sulfur, potassium and manganese can also be found in wood, as can heavy metals.

In recent years, the need to understand the basis for, and implications of, wood quality variability has been driven by moves towards sophisticated engineered wood composites and products. This industrial need for convenient access to fundamental wood quality information has in turn driven the development of a suite of rapid assessment tools, combining unique high-throughput methods for examining physical and chemical variability ("phenotyping") with state-of-the-art genomics tools to examine the underlying genetics of that variability. A major gap in this field is knowledge of the impact of trace elements on wood products and processing. This is in spite of the fact that there is a growing body of evidence to suggest that the trace elemental composition of wood directly impacts on its ultimate utility. High silica levels are well known to cause accelerated tool wear and to reduce lumber manufacturing yield, and to lead to staining in the drying process [1b]. It has further been suggested that trace elements can influence wood pH in terms of its buffering capacity, reducing the rate of adhesive curing [2]; can impact on pulping chemistry [3]; reduce photo-yellowing resistance in paper [4] and affect the thermal decomposition of wood, directly influencing the composition of bio-oils from pyrolysis [5].

Although a number of techniques have been examined for determining the chemical, physical and mechanical properties of wood and wood products, work to date has, from a chemistry perspective, focused almost exclusively on their organic composition neglecting the inorganic trace elements [6]. This focus should be interpreted in light of the fact that there has been historically a paucity of analytical techniques available for the analysis of trace elements in wood. Early studies used atomic absorption spectroscopy, but high detection limits and an inability to perform multi-element analyses have limited its use [7]. Similar practical limitations have also restricted the use of alternative techniques such as laser-ablation ICP-MS, secondary ion MS and photon-induced x-ray emission spectroscopy [8].

As the value-chain paradigm for forest industries is moving away from commodities and towards more sophisticated engineered wood products and composites, this generates an industry-wide requirement for access to fundamental wood quality information that impacts on raw material performance and processability. It is likely that elemental composition is of critical importance for many industrial processes. The development of a rapid assessment technology for the inorganic components of wood would be a valuable addition to the extant suite of tools developed for its organic constituents, mechanical and physical properties and would provide an extra dimension to the evaluation of wood suitability for given products. Laser-induced breakdown spectroscopy (LIBS) is the most promising such technology, but has not been widely used outside of the laboratory, other than in the analysis of the levels of inorganic contaminants in waste wood to be used for recycling. The development of a robust field and mill-capable instrument could yield many specific benefits to the industry including:

- the monitoring of wood silica levels
- investigation of inorganic components' effects on pulping chemistry and paper yellowing (*scaling deposits, corrosion, recovery boiler plugging, inerts in lime cycle, effects on TCF bleaching, environmental impacts*)
- the examination of metal cations' effects on the thermal decomposition of wood
- detection of heartwood/sapwood
- identification of wood via spectral signatures (subject to ability to internally ratio constituent metals to develop association patterns)
- detection of "wetwood" (associated with increased mineral content)
- detection of incipient decay (early decay being associated with elevated levels of heavier elements)
- Separation of contaminated waste wood from timber diverted from landfill.

Perhaps the most immediate application of the technology, however, would be to monitor the pH of wood (its buffering capacity), a property which is known to affect adhesives cure rate [2]. Urea-formaldehyde resins and isocyanate resins, which require an acidic environment for cure, are strongly influenced by the pH of the wood substrate. This buffering capacity is determined by extracellular molecules and trace elements and can alter the pH of the applied adhesive formulation, significantly reducing the cure rate of the resin and ultimately the properties of the product. In spite of this property's importance, the time and expense involved in its determination has meant that there has been limited research to date addressing the issue. The application of the rapid assessment LIBS technology would create the foundation for the development of a rapid, affordable technique for on-line/at-line monitoring of wood pH and related variables. This may present a unique opportunity to examine the interaction between adhesive resin formulations and given species of industrial wood, enabling the optimisation of adhesive bonding variables. Additionally, if LIBS could detect the pH of green wood, it may be useful for detecting collapse-prone ash eucalypts (E. regnans, E. delegatensis, E. nitens, *E. viminalis*) given the relationship between acidic wood and collapse susceptibility [12].

The first task of this project was, therefore, to take LIBS spectra from a series of radiata pine samples and to detect and quantify a series of important inorganic elements (beginning with calcium and sodium) using a suite of statistical techinques.

Penetration of adhesive resins into the wood substrate is a necessary criterion for the formation of strong, durable adhesive bonds. Resin formulation variables like molecular

weight and molecular weight distribution are routinely utilised to manipulate and optimise this aspect of adhesive bonding in wood. While a number of methods have been developed to measure penetration of the organic phase of the resin into the wood substrate, there are no reports extant relative to the diffusion of the bonding catalyst (typically NaOH) through the polymer matrix of the cell wall. It has been indirectly demonstrated that mobility in the cell wall matrix is related to ion size (e.g. sodium > potassium > calcium), and that this may impact resin cure. Changes in catalyst concentration within the cure environment would likely lead to heterogeneous development of network structure, creating defects in the bondline, contributing to premature failure.

The second task of this project was to produce adhesive bondlines using selected wood samples with urea-formaldehyde resins varying in their viscosity and catalyst content. LIBS data were then collected across the wood-adhesive joint to define catalyst location at high spatial resolution to investigate the penetration of the polymeric adhesive phase and the chemical structure of the cured resin.

#### Laser-induced breakdown spectroscopy

Laser-induced breakdown spectroscopy (LIBS) is an emergent technology, used as a diagnostic technique for monitoring the inorganic elemental composition of solids, liquids and gases. The technology is based on a pulsed laser with a power high enough to form a plasma in the medium to be studied. The plasma temperature – 10,000-25,000K – is sufficient to dissociate molecules into their constituent atoms where the field intensity initiates an avalanche ionization of the sample elements – the "breakdown" effect. The electrons of these dissociated atoms within the energetic plasma gain enough energy to move from their ground states to excited states. Subsequently, the atoms undergo atomic emission to relax back to their ground states, in the process emitting light of characteristic wavelengths. Each element has, therefore, a unique "fingerprint" of emission lines enabling spectral identification and quantification. This ability to fingerprint elemental composition enables real-time identification of elements in a sample; the monitoring of multiple elements at once and depth profiling and spatial mapping of elements within a sample. Additionally, LIBS instrumentation (Figure 1) is composed of mainly solid-state components with few moving parts and requires minimal sample preparation.

LIBS is a relatively simple spark spectrochemical technique that uses a short-pulsed laser (~7 ns) focused on the sample to be interrogated to create a microplasma. The microplasma/spark is a transient event where the peak temperature reaches 10,000 – 20,000 K. In this environment the sample is converted into plasma and the chemical bonds are broken to produce electronically excited atoms and ions. These excited species give off resonant and sharp radiation at specific wavelengths depending on the element. By capturing the light from the microplasma within the 200-980 nm range the following is accomplished: (1) elements are identified by their specific wavelengths, (2) chemical abundances are measured by the intensity of the light at specific wavelengths, and (3) all matter is detected since all elements emit somewhere in the 200-980 nm range.

LIBS is also real-time (response time less than a second) and is inherently very sensitive because only a tiny amount of matter (picogram to nanogram) is engaged in the microplasma each time a laser fires. The LIBS event generates a tremendous amount of data and every laser shot produces a usable spectrum. Furthermore, LIBS is very good at detecting small particles, especially when the size of the particle is on the same order as 20-30 the micron diameter of the focused laser beam. Experimentally, it is much simpler than mass spectrometry, the most popular characterization technique, as LIBS can operate at atmospheric pressure in order to produce useful plasma emission intensities. The actual plasma emission is characterized by a continuum spectrum (bremsstrahlung emission) and discrete emission lines. The continuum emission and the discrete emission, from both atoms and ions, decay with time at different rates. While the continuum emission decays fast within a few microseconds, the discrete emission persist strongly on the order of tens of microseconds. The plasma emission can, therefore, be resolved both spectrally and temporally to yield spectra containing the atomic emission lines corresponding to the atoms present in the plasma volume.



*Figure 1: Schematic diagram of a Laser-Induced Breakdown Spectroscopy (LIBS) system. Graphic courtesy of Applied Photonics Ltd.* 

Geometric factors, such as the distance between the sample and the focusing lens and the method of collecting the plasma light, can greatly influence the analytical results. To obtain the best quantitative results, one must consider this geometry. Multari et al. [9] report the results of an investigation of the effect of sampling geometry on LIBS measurements. Diagnostics include time-resolved spectroscopy and temporally and spectrally resolved imaging using an acousto-optic tunable filter (AOTF). Parameters investigated include the type of lens (cylindrical or spherical) used to focus the laser pulse onto the sample, the focal length of the lens (75 or 150 mm), the lens-to-sample distance (LTSD), the angle-of-incidence of the laser pulse onto the sample, and the method used to collect the plasma light (lens or fiber-optic bundle). From these studies, it was found that atomic emission intensities, plasma temperature, and mass of ablated

material depend strongly on the LTSD for both types of lenses. For laser pulse energies above the breakdown threshold for air, these quantities exhibit symmetric behavior about a LTSD approximately equal to the back focal length for cylindrical lenses and asymmetric behavior for spherical lenses. For pulse energies below the air breakdown threshold, results obtained for both lenses display symmetric behavior. Detection limits and measurement precision for the elements Be, Cr, Cu, Mn, Pb, and Sr, determined with the use of 14 certified reference soils and stream sediments, were found to be independent of the lens used. Time-resolved images of the laser plasma show that at times >5 microsec after plasma formation a cloud of emitting atoms extends significantly beyond the centrally located, visibly white, intense plasma core present at early times (<0.3 microsec). It was determined that, by collecting light from the edges of the emitting cloud, one can record spectra using an ungated detector (no time resolution) that resemble closely the spectra obtained from a gated detector providing time-resolved detection. This result has implications in the development of less expensive LIBS detection systems.

### Equipment

Preliminary project work has been undertaken at the Oak Ridge National Laboratory (Oak Ridge, TN, USA) using their LIBS equipment (Figure 2). This consists of a Spectra Physics Laser, model INDI-50 (Mountain View, CA, USA). This is a Q-switched Nd:YAG laser with output wavelengths at the fundamental wavelength of 1064 nm, frequency doubled to 532 nm and frequency quadrupled to 266 nm. Maximum beam energies at 1064, 532 and 266 nm respectively are 500, 250 and 80 mJ per pulse. Laser pulse width is 6-8 ns with a repetition rate of 10 Hz. The entire analytical process – plasma formation, emission, gated detection, data collection and analysis – is completed within 100 ms.



Figure 2: Spectra Physics Nd:YAG laser set-up at ORNL.

#### Study tour: the Oak Ridge National Laboratory

The Oak Ridge National Laboratory is the U.S. Department of Energy's largest science and energy laboratory. Managed since April 2000 by a partnership of the University of Tennessee and Battelle, the ORNL was originally established in 1943 as a part of the top secret Manhattan project. Its principal role was in the development of methods to produce and separate plutonium. During the 1950's and 60's, the ORNL evolved into an international centre for the study of nuclear energy and related research fields in the physical and life sciences. More recently, the Laboratory's research portfolio has expanded into areas of energy production, transmission and conservation. ORNL has a staff of more than 4,000 and annually hosts up to 3,000 guest researchers who typically spend two weeks or longer at the facility. In the 2005 financial year, ORNL funding exceeded USD \$1 billion.

The Environmental Sciences Division (ESD) of the ORNL is an interdisciplinary research and development organization with more than 60 years of achievement in local, national, and international environmental research. The ESD vision is to expand scientific knowledge and develop innovative strategies and technologies that will strengthen the nation's leadership in creating solutions to help sustain the Earth's natural resources. Scientists in ESD conduct research, develop technology, and perform analyses to understand and assess responses of environmental systems at the environment-human interface and the consequences of alternative energy and environmental strategies. They seek to understand how natural and anthropogenic factors (e.g., global and regional change, environmental stress, and energy production and use) interact to influence environmental systems and society. ESD methods integrate field and laboratory methods with new theory, modeling, data systems, policy analysis, and evaluation to create solutions to complex environmental challenges.

#### **Project outline and progress to date**

The objective of this project is to design, apply and evaluate a LIBS system capable of the rapid, accurate and simultaneous multi-elemental analysis of wood and wood products. The development of an optimised rapid LIBS systems would yield the following major benefits to the industry:

(a) monitoring silica (Si) levels, which are known to cause accelerated tool wear, reduction of lumber yield and staining during drying (lumber industry)

(b) investigating inorganic components' effects on pulping chemistry (e.g. Ca, Al and Si on scaling etc.) and paper yellowing (pulp and paper industry; Mg on corrosion, K and Cl in recovery boiler plugging).

(c) examining metal cations' effects on the thermal decomposition of wood (forestry)(d) monitoring the buffering capacity of wood, a property which is known to affect adhesives cure rate (wood composites industry) and which could rapidly detect collapse-prone stems.

(e) development of spectral fingerprints for wood identification

(f) detection of incipient decay in standing trees (early decay being associated with elevated levels of heavier elements, e.g. N, P, Pb)

(g) detect contaminants in the waste wood stream and divert contaminated waste wood from the timber suitable for recycling .

Previous work at the Oak Ridge National Laboratory's LIBS facility has provided preliminary evidence that spectral signatures specific to calcium, sodium and magnesium can be readily detected in samples of Oak wood (*Quercus spp.*). These results are shown in Figure 3.



Figure 3: Detection of three trace elements in a wood sample using LIBS.

These results are, however, qualitative rather than quantitative in nature. To remedy this, a major objective of the current study was to link LIBS with standard analytical techniques (such as ICP-AES) and use multi-variate statistics to generate calibration curves for 20 elements present in wood. To achieve this, standard wood samples for analysis have been developed. These samples consist of pellets of cellulose powder, formed under a pressure of 110 MPa for 1 min and doped with increasing concentrations of multi-element standard solutions. The final densities of the pellets were chosen to match those of wood. Pre-ablation prior to analysis will remove possible contamination from the pellets. These standard samples were constituted by ORNL prior to the commencement of the study, having been used in their initial Oak work [11]. Calibration data are currently confidential to ORNL, but will be published in due course in the open literature.

Ten laser pulses were directed onto the wood samples to complete a single measurement. The marking left on a typical sample of radiata pine is shown in Figure 4. Because of shot-to-shot variation in laser plasma parameters and sampling geometry, measurement precision was increased by ratioing the analyte signal to the signal from carbon (found at the same concentration in all samples). The accuracy of calibration using LIBS was verified by digestion of the pellets and analysis using ICP-AES (as in

[11]). A minimum detection limit for all of the elements was established and measurement precision determined by performing 12 replicate measurements. Sampling was performed by taking each sample (cube or rectangular) and placed with the laser beam focused at right angles to the surface of the sample. This was done under ambient air temp and pressure. Also the experimental parameters were:

- 1. Laser wavelength 532 nm
- 2. Laser pulse width 4 nsec.
- 3. Laser rep rate 2 Hz.
- 4. Laser energy/pulse 45mJ

5. Number of shots used to get each spectra - 10.

This was kept constant for all the data that was acquired.



Figure 4: Sample marking after LIBS analysis. Resolution of 1 micron is possible.

All element-specific ionization peaks within the spectral range of 200-800 nm were identified using the GRAMS/AI (Thermo Galactic, NH, USA) data processing and management package. The software incorporates emission peak identification with analytical and graphic interface capabilities. Peaks were independently checked against the NIST Atomic Spectral database (<u>http://www.nist.gov/srd/</u>).

LIBS spectra data are complex representations of the inorganic constituents of the samples. Each spectrum consists of more than 7500 data points and so the principal processing challenge in interpretation of the data is to isolate spectral variables that can be correlated to different chemical signatures within the samples. Appendix 3 collates a series of raw spectral data, indicating the wavelength ranges scanned and the sample

variability is clearly visible even to a cursory inspection. Three LIBS spectra were collected for each sample and reduced to 0.08 nm wavelength spacing. Multiplicative scattering correction (MSC) was then applied to all data prior to analysis. MSC, described in Martens and Naes [10] is a transformation method used to compensate for additive and/or multiplicative effects in the spectra.



Figure 5: Initial calibration for Ca, Na ions using loblolly pine samples

Element	Spectral transition (nm)
Са	393.38; 396.82; 422.66; 428.90; 430.26;
	558.26
Na	588.98; 589.54

*Table I: Identified chemical elements and related LIBS emission lines – calibration Loblolly pine set..* 





*Figure 6: Two radiata pine samples (1, 30) analysed for elemental content – Top – bottom: Sample 1 LIBS spectrum showing annotated elements; Sample 1 LIBS spectrum expanded to separate close peaks for Na and Si; Sample 30 LIBS annotated LIBS spectrum.* 

## LIBS experimental results – Part 1: Element identification

Figure 5 shows an initial calibration experiment undertaken using previously characterized Loblolly pine samples NW7 and NB10 (codes developed by, and confidential to ORNL). This experiment confirmed that the LIBS equipment was working properly and delivering elemental spectral identification in a reproducible fashion [11]. Figure 6 then shows LIBS spectra for two radiata pine samples sourced from an industrial collaborator. The spectra, produced according to methods described in the previous section, have been annotated for inorganic elements of industrial interest: Mg, Al, Ca, Ti, Na and Si. The middle panel of Figure 6 shows and exploded region of the spectrum for Sample 1, allowing visual inspection of closely aligned peaks for two of the elements, Na and Si. Details on the spectral transitions in nm which allow a "spectral fingerprint" identification of elements and samples are shown for the calibration set in Table I and the experimental sets in Table II.

Element	Spectral transition (nm)
Mg	383.78; 384.02
Al	393.29; 396.08
Са	394.34; 396.80; 422.60; 430.70
Ti	445.38; 453.48
Na	588.90; 589.52
Si	623.54; 624.18; 779.82

*Table II: Identified chemical elements and related LIBS emission lines – Experimental radiata pine sets.* 

### LIBS experimental results – Part 2: Investigation of wood-resin interactions

Following initial experimental calibration experiments, selected wood samples were taken from the experimental set and adhesive bondlines produced for analysis. The bonds were prepared using urea-formaldehyde resins varying in viscosity and catalyst content. LIBS data were collected across the wood-resin-wood joint at high spatial resolution to characterize the catalyst location and to determine the penetration of the polymeric phase into the wood substrate – a critical parameter for bonding efficacy. A preliminary LIBS scan of such a joint is shown in Figure 7. The scan, using Na as indicator of catalyst presence, clearly indicates the presence of the catalyst across the sample joint, with a peak in the resin-concentrated area. Principal component analysis [11] of the data (shown in the bottom panel of Figure 7) has been used to remove redundancy in the data set, transforming it into a few loadings which contain the most valuable spectral information – relating to the spatial distribution throughout the sample of the resin catalyst. Further experiments in this area will be directed to examining the resin penetration in varying substrates and the effects of alterations to the resin formulation.



Figure 7: LIBS spectral data used to examine spatial distribution of resin throughout a wood-resin-wood interface. Top, raw data. Bottom, loading of the principal component 1 of LIBS spectra for all datasets.

#### Summary

Laser-induced breakdown spectroscopy is a rapid, reproducible, non-destructive technology used to examine the inorganic composition of samples sourced from a variety of materials. Whilst it has been employed in the forest and forest products industry before, its use has largely been confined to examining the contamination levels of preservatives such as CCA in treated timber found in waste-wood streams. This project suggests that LIBS may have much broader applications in the industry, dependent on its ability to detect and quantify other elements common to untreated timbers.

Data are presented to confirm the ability of LIBS technology to detect several elements of industrial interest. Si, which can be detected, is implicated in accelerated tool wear in mills. Ca is known to impact on scaling in pulp mills and on paper yellowing. Mg is thought to be an indicator of decay propensity in standing wood. A rapid method for monitoring the wood content of such samples, particularly if the technology could be further developed as an on-line system, will be of great advantage in pre-and post-harvest segregation of timbers and optimization of processing parameters.

A potential application of the technology has been examined in a preliminary experiment. Na has been detected as an indicator of resin penetration in a bondline produced between selected wood samples. LIBS technology has been demonstrated to be capable of monitoring the distribution of Na around and within the resin layer, opening up the possibility to non-destructively examine resin penetration into various wood substrates. This will enable the optimization of resin formulations for specific wood types with the end-goal of reducing the incidence of premature failure in bondlines caused by hitherto undetectable resin-wood interface defects. Further experiments will determine the detection limit of sodium within the woody matrix to evaluate the potential utility of this approach to periodic QC sampling of wood composite products.

An alliance to explore and develop LIBS technology for applications in the industry has been established with a world-leader in this research area, the ORNL in Tennessee, USA.

#### Acknowledgements

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#### **Appendix 1: Travel Itinerary**

15 January, 2006 – Travel to Oak Ridge Tennessee
17 – 31 January, 2006 – LIBS laboratory work, spectra collection and data analysis at ORNL and University of Tennessee laboratories.
4 February, 2006 – Return to Melbourne

#### **Appendix 2: Contact details**

Dr. Madhavi S. Martin, Environmental Sciences Division, Oak Ridge National Laboratory, P.O. Box 2008 MS 6422, Oak Ridge, TN 37831-6422, U.S.A.

Forest Products Center, University of Tennessee, 2506 Jacob Drive, Knoxville, TN 37996-4570, U.S.A.



Appendix 3: Raw spectral data















