Stream 2.3 and 2.4: Industry Applications

1. Abstract:

This stream was established in order to provide grape and wine producers with knowledge, methods and tools which would allow them to improve, streamline and reduce the cost of their production processes. The rationale was to add value to the outputs of previous and concurrent research by further developing those outputs into a form where they could be adopted by industry; a process often informed by working in close collaboration with grape and wine producers. A two-stage process was instigated whereby the research outputs with the greatest potential to provide understanding, methods, or tools were identified and developed, with project staff then working with grape and wine producers to ensure adoption of the resulting technology. This strategy also encompassed the establishment of regional nodes of the AWRI (Stream 4.4), which have proven to be excellent vehicles through which to conduct development work, and to foster adoption.

Many of the research outputs taken through this development and adoption process were those that had emerged from previous research into the application of spectroscopy in the grape and wine sector. A number of tools which represent a paradigm shift in the way grapes and wines are analysed have been developed by this stream, spanning the value chain from vineyard to consumers. These include:

- A web-based tool for the simultaneous measurement of tannin and several other characteristics related to grape and wine phenolic composition.
- Several applications of the concept of spectral fingerprinting, including: a labelling device which enables consumers to be aware of the style of wine in the bottle pre-purchase; and an instrument which allows wine to be analysed non-destructively in-bottle.
- Analytical methods for a number of grape and must compositional variables, which provide more rapid measurement and have greater scope than previously available techniques.

Other outcomes of the stream include:

- The development of research which had identified a viable enzymatic alternative to bentonite fining into a workable winemaking process modification.
- Extensive phenotypic characterisation of strains of the spoilage yeast *Brettanomyces* (isolated from Australian wines), which identified sulfite tolerance as the main differentiating characteristic.
- An evaluation of the efficacy of using grape stalks and marc for the production of renewable energy.
- A fermentation modelling tool which facilitates optimisation of fermentation performance to maximise wine quality; provides early warning of problem fermentations; as well as the ability to manage refrigeration use in order to reduce power consumption and avoid punitive electricity tariffs.
- Extensive understanding of the kinetics and physical conditions which govern the extraction of phenolics during the production of Pinot Noir red wines, including a technique utilising microwave treatment of must to allow full phenolic extraction pre-fermentation – a technique which is also applicable to other grape varieties.
- The development of knowledge on the distribution of rotundone (the ‘black pepper’ compound found in Shiraz and other wines) in Shiraz grapes of different clones grown in a number of locations.

Early work in the stream sought to understand potential barriers to adoption which were likely to be encountered. The model that was developed as a consequence, comprising concurrent development and adoption in close collaboration with industry partners via regional nodes, has proven to be successful. The efficacies of the outcomes discussed here were demonstrated in commercial settings and extensive industry adoption has occurred.

2. Executive summary:

The rationale of the stream was to add value to the outputs of previous and concurrent research by further developing those outputs into industry applicable knowledge, methods and tools. The broad objective was to foster adoption of that knowledge, methods and tools in order to improve the economic and environmental sustainability, profitability, and competitiveness of the Australian wine sector. The research outputs selected for development were those assessed as having the greatest potential to improve and streamline production processes, while reducing cost and maximising wine quality. Part of the strategy was also to ensure that existing objective measures of grape and wine composition were developed into more simplified methods which would encourage their adoption.

The stream has successfully generated an extensive suite of outcomes which have been made available to the grape and wine sector and extensive industry adoption of these outcomes has occurred. For some, development is complete, and for others, further industry evaluation and adaption will be required before a fully evolved product is available for widespread industry adoption.

Many of the research outputs taken through the development and adoption process described here were those that had emerged from previous research into the application of spectroscopy in the grape and wine sector. A number of novel spectroscopy tools have been developed which span the value chain from vineyard to consumers, several of which are 'world firsts'. They include:

- A web-based tool for the simultaneous measurement of tannin and several other characteristics related to grape and wine phenolic composition, known as the WineCloud^{TM}.
- Several analytical methods for grape and must compositional variables, which allow more rapid measurement and have greater scope than previously available techniques. Two of the methods that offer the greatest benefit for the industry are for measuring grape colour and yeast assimilable nitrogen (YAN) in juices and musts.
- The PinotG Style Spectrum^{TM} is a wine labelling device which enables consumers to be aware the style of the wine in the bottle before they purchase or consume it.
- BevScan^{TM} is a spectrophotometer which allows wine to be analysed in-bottle non-destructively.

Spectral fingerprinting allows wine style to be 'measured'; a concept which has potentially important implications for the way grapes are grown; selected; paid for; and for how wines are produced. A spectral fingerprint can be considered as an objective and holistic target of wine style, meaning that the degree to which various winemaking treatments contribute to producing a targeted wine style can be assessed objectively. In theory, the concept could also be applied to grapes to select those which best allow the desired wine style to be produced, thus adding value to those grapes; and also applied to growing grapes to meet objectively defined target fingerprints. The technique is also applicable to assessing wine authenticity and integrity.

A further outcome of the stream is ground-breaking and raises the potential for fundamental changes in the way white wines are produced. Research in Stream 2.2 which had identified a viable enzymatic alternative to bentonite fining was developed into a workable winemaking process modification in collaboration with two commercial wine producers. This technique makes it possible to render white, sparkling, and rose wines 'heat' or protein-stable pre- fermentation, through a relatively simple enzyme addition combined with heating. This technique provides a profound increase in production efficiency and reduction in cost, compared with traditional batch bentonite fining.

Other outcomes of the stream include:

- Extensive phenotypic characterisation of strains of the spoilage yeast *Brettanomyces* (isolated from Australian wines) which identified sulfite tolerance as the main differentiating characteristic and provided invaluable information for developing effective management practices (this work was progressed further in Stream 2.1).
- An evaluation of the use of grape stalks and marc as a source of renewable energy. Objective data has been generated on which decisions to invest in electricity-generating equipment can be based, and at least one tender for the construction of such a plant has been released during the life of this stream.
- A fermentation simulation tool which allows optimisation of fermentation performance; early identification of problem fermentations; as well as the ability to manage refrigeration use to

reduce power consumption and avoid punitive electricity tariffs.
- The development of knowledge on the distribution of rotundone (the 'black pepper' compound found in Shiraz wines) in Shiraz grapes of different clones grown in a number of locations.

Additionally, other foundational spectroscopy work conducted under this stream (but not reported in detail here) includes the:
- generation of evidence linking soil composition and grape and wine composition, in a number of trials;
- differentiation of wines produced organically and non-organically; and
- differentiation of wines of the same variety by country of origin.

The efficacies of most of the technologies discussed here have been demonstrated in commercial settings and extensive industry adoption. However, most technologies could be further developed and extended to provide even greater value to industry; the investment required to do so would be marginal compared to the value generated.

Early work in the stream sought to understand potential barriers to adoption which were likely to be encountered. The model developed comprised concurrent development and adoption, in close collaboration with industry partners via regional nodes, and has proven to be successful. The AWRI's network of regional nodes has been crucial to delivering value to industry through conducting both development and adoption activities. The nodes form a crucial part of the adoption strategy, but were established relatively late in the AWRI's 7-year RD&E Plan. Their success in this regard has been demonstrated, however, their full value has yet to be realised.

Many of the outputs of this stream are suited to web-based application; the efficacy of which has been demonstrated with the phenolic analyses made available to industry via the WineCloud. The WineCloud has the potential to be extended to incorporate the fermentation simulation model described here, as well as the creation of a module which allows users to conduct advanced statistical benchmarking of their own data against the vast library of data which would be held in the WineCloud.

Potential also exists to extend the concept of modelling beyond fermentation to other parts of the grape and wine production process and to incorporate such models into the WineCloud. Such modelling requires real-time data to be available on which to base predictions and assessments of the conditions of a wine, compared to known standards or specifications. An obvious opportunity therefore exists to invest in the development and adoption of process analytical technologies which have been tailored to the requirements of the grape and wine sector, in order to gather such data in an automated way and feed it into such models in real time.

Affiliation	**Area of support/contribution**
Keith Tulloch Wine	Support for Hunter Node office
Tasmanian Institute of Agriculture	Funding and support for Tasmania Node
TAFE Griffith	Support for Riverina Node office
CAMO Australia	BevScan software
Jeffress Engineering	BevScan hardware
De Bortoli Wines	Grape and wine process efficiency, ferment simulator, rapid measurement of grape and wine attributes, grape and wine portal, Proctase field trials
Casella Wines	Ferment simulator, rapid measurement of grape and wine attributes, grape and wine portal
McWilliam's Wines	Ferment simulator, rapid measurement of grape and wine attributes, grape and wine portal
Riverina Winegrapes Marketing Board	Rapid measurement of grape and wine attributes, grape and wine portal
Westend Estate	Rapid measurement of grape and wine attributes, grape and wine portal

Affiliation	Area of support/contribution
Warburn Estate	Rapid measurement of grape and wine attributes, grape and wine portal
Bimbadgen	Grape and wine process efficiency, ferment simulator, Semillon regionality, rapid measurement of grape and wine attributes, grape and wine portal
Brokenwood	Grape and wine process efficiency, ferment simulator, Semillon regionality, rapid measurement of grape and wine attributes, grape and wine portal
McWilliam's Wines, Mt Pleasant	Grape and wine process efficiency, ferment simulator, Semillon regionality, rapid measurement of grape and wine attributes, grape and wine portal
Oakvale	Grape and wine process efficiency, ferment simulator, Semillon regionality, rapid measurement of grape and wine attributes, grape and wine portal
Poole's Rock	Grape and wine process efficiency, ferment simulator, Semillon regionality, rapid measurement of grape and wine attributes, grape and wine portal
Wynns Coonawarra Estate	Grape and wine composition
University of Adelaide	Energy from winery by-products
University of Sheffield	Characterisation and sensory impact of *Brettanomyces*
Treasury Wine Estates	Chardonnay Style Spectrum, Pinot G Style Spectrum, characterisation and sensory impact of *Brettanomyces*
Cellarmaster Wines	Pinot G Style Spectrum
The Yalumba Wine Company	Pinot G Style Spectrum
Domaine Paul Blanck, Alsace, France	Pinot G Style Spectrum
Frogmore Creek	Pinot Noir regionality through process modification
Winemaking Tasmania	Pinot Noir regionality through process modification; BevScan in bottle ferment monitoring
Pressing Matters	Pinot Noir regionality through process modification
Josef Chromy	Pinot Noir regionality through process modification
Tamar Ridge	Pinot Noir regionality through process modification
Springvale Wines	Pinot Noir regionality through process modification
Pirie Tasmania	Pinot Noir regionality through process modification, BevScan in bottle ferment monitoring
Jansz Tasmania	Monitoring sparkling wine development using BevScan
The Yalumba Wine Company	Monitoring sparkling wine development using BevScan, Proctase field trials
Bruker Instruments	Bruker Alpha calibration development
Petaluma Wines	Bruker Alpha calibration development
Glandore	Semillon regionality project
First Creek	Semillon regionality project
Thomas Wines	Semillon regionality project
Peppertree	Semillon regionality project
Deakin University	Shiraz clonal evaluation of rotundone
The Yalumba Wine Company	Shiraz clonal evaluation of rotundone
The Department of Agriculture (Science and Innovation Award)	Assessment of calorific value of grape marc and stalks

3. Background:

This stream was initiated in its current form on 1 July 2008, by consolidating the following streams in the AWRI 7-Year RD&E Plan: 2.3 Process Measurement, 2.4 Industry Applications, and 3.4 Environmental Impact and Sustainability. New stream and project plans were prepared to replace those in the original AWRI 7-Year RD&E Plan. The rationale behind doing this was to add further value to investments made in research, by creating a vehicle which was specifically tasked with actively developing outputs into understanding, methods and tools and to foster their adoption by grape and wine producers. Simply stated, the aim was to turn research outputs into industry-relevant outcomes.

This report discusses work performed pre and post the commencement of this stream in its current form in July 2008.

The instigation of this stream in 2008 formed part of the AWRI's strategy to address the call for national R (research), with regional D (development) & local E (extension) including 'regional adaptive development', which had been made by the Primary Industries Ministerial Council (PIMC). That concept was later formalised by the PIMC in 2009, in the National Primary Industries RDE Framework (http://www.daff.gov.au/agriculture-food/innovation/national-primary-industries). The formation of the nodes was seen as an ideal mechanism for delivering regional adaptive development of research outputs into value-adding outcomes for industry.

The expected outcomes were:
- Increased industry access to application-ready technologies which have the ability to add value and reduce costs during the grape and wine production process – leading to improved process efficiency and productivity.
- A consequential reduction in environmental impact and improved industry sustainability.
- Increased knowledge and capability of industry personnel.
- Increased access to rapid analytical and other 'smart' technologies to assist in improved decision management.
- Increased understanding of the key compositional and processing variables that impact on wine quality and consumer value.
- Improved industry access to process engineering and environmental-impact reduction expertise. Enhanced opportunities for AWRI commercial activities to sell application-ready technologies outside of the grape and wine industry levy-paying base, with any surplus being invested in grape and wine research.

The stream will act as a multiplier on previous industry investments in R&D, by combining existing and novel research outputs in innovative ways.

This stream applied staff dedicated to coordinating and driving development and adoption to ensure the full potential of research findings is realised by industry. This approach built on a coordinated development and adoption approach that had been trialled with two research projects: research into wine bottle closures and into *Brettanomyces* spoilage yeast. Research, development, extension and adoption were conducted on these projects and managed concurrently by a dedicated team. Both those projects had resulted in a high level of practice change by industry and the success of that model guided the formation of this stream.

4. Stream objectives:

The objectives of this stream were:
- Increase industry access to application-ready technologies that have the ability to add value and reduce costs during the grape and wine production process.
- Increase access to rapid analytical and other 'smart' technologies to assist in improved decision making.

- Increase understanding of the key compositional and processing variables that impact on wine quality and consumer value.
- Improve industry access to process engineering and environmental-impact reduction expertise.
- Help to reduce the environmental impact and improve sustainability of the wine industry, by identifying potential opportunities for the application of environmental engineering principles to grape and wine processing operations.
- Demonstrate through specific studies the benefits to the environment of adoption of alternative 'green' technologies.
- Understand the critical factors, cultural and environmental, contributing to the relative propensity of red wines to undergo *Brettanomyces*-related spoilage.
- Develop effective *Brettanomyces* control mechanisms, where possible specific to strain and wine composition differences, in order to minimise collateral negative effects on wine quality and style.
- Define the differences between sensory characteristics of wines that are and those that are not spoilt by *Brettanomyces* under Australian conditions, and identify the important changes that occur in the chemical composition of wines when they undergo spoilage.
- Provide tools and training to the industry enabling it to estimate and eliminate the risk of *Brettanomyces*-related spoilage based upon defined wine or strain properties.

5. Methodology:

The rationale behind this stream was to add value to the outputs of previous and concurrent research by further developing those outputs into a form where they could be adopted by industry. The aim was to provide grape and wine producers with knowledge, methods and tools which would allow them to improve, streamline and reduce the cost of their production processes. It was also recognised that the speed at which new R&D is adopted by industry is a key competitive advantage for the Australian grape and wine sector and is a crucial factor if the return on industry investments in RD&E is to be maximised.
The AWRI's strategy to deliver rapid development and adoption of research outputs into valuable industry outcomes, comprised this stream and the establishment of regional nodes (Stream 4.4), to provide the regional adaptive development called for by the Primary Industries Ministerial Council (PIMC) in 2005.

Nodes were established in Tasmania on a 0.2 FTE basis in November 2008, and a 1.0 FTE basis in July 2011; in the Riverina in November 2010; in southern Victoria in January 2012 (which is not funded as part of the GWRDC-AWRI Investment Agreement); and in the Hunter Valley in September 2012. Details of the establishment of the nodes and outputs delivered through them are provided in the report for Stream 4.4.

The development projects pursued under this stream were selected on the basis of their potential to provide the greatest benefit for industry, their alignment with regionally-defined priorities and the applicability of resulting outputs to the broader grape and wine sector. Personnel funded within this stream work in close contact with research staff, in order to remain aware of potential research findings which could be developed and targeted for industry use. Each node has a single staff member and, in each case, they participate on local regional industry association technical committees in which regional R&D priorities are set. Node staff are able to inform discussions of regional priorities with regard to new research findings from the AWRI and elsewhere; seeking to identify synergies between research findings and how they might fit with regional priorities. Once projects have been selected, they are in most cases planned and project managed by Adelaide-based AWRI staff in conjunction with the node staff members.

Much of the development work described here has been conducted in close collaboration with industry partners via the regional nodes network, where local wineries were used as test sites in which new knowledge, methods and tools were fully developed and adapted to best meet industry needs. The close collaboration with industry partners and the use of local production facilities provided in-depth knowledge of the imperatives that need to be met if new knowledge, methods or tools are to be widely adopted by industry. This specifically guided the development of the new technologies described here, in order for them to be compatible with existing processing systems used by different producers.

This adaptive development process often led to the industry partners being early adopters of the new technologies. The strategies used to encourage the further spread of adoption are based on work which commenced with the Department of Primary Industries Victoria's Practice Change Group in 2008, to understand the barriers to adoption of new technology by industry.

In collaboration with the Practice Change Group, wine industry attitudes and approaches to testing compositional variables in grapes and wine were surveyed. Participants were asked: what tests they were performing; what would they like to test; and how and from where they received information on what they should be testing and which methods they should be adopting. The information gained from that survey has been important in focusing much of the work conducted in this stream on simplifying and extending the availability of objective measures of grape and wine composition.

In addition, previous work by the Practice Change Group in other agricultural industries had identified patterns of how new technologies were adopted by industry participants. First mover adoption was followed by adoption by neighbouring properties, and then by individual properties often some distance away. Investigation identified that those more distant properties always had a personal connection to the first-mover properties and personal endorsement was the key to the spread of the technology. Properties neighbouring those more distant ones then became the next wave of adopters and the cycle was repeated. This stream has sought to capitalise on that knowledge in adoption methodology.

The node network forms a crucial part of that adoption strategy with the aim being to foster first- mover adoption by node collaborators, and then encouraging adoption to spread to other producers in that region. Many of the technologies developed by this stream are relatively complex and represent a paradigm shift in the way grapes and wines are processed and analysed; consequently a hands-on approach to fostering first mover adoption has been necessary. However, collaborating wine producers are best able to recognise the value of the new technology, to become early adopters and provide endorsements of the value of the technology.

Once a degree of first-mover adoption has been achieved, case studies of the adoption fostered within the nodes have been taken to other producers and regions via the node network and via the AWRI's extension activities, prompting wider adoption. Additionally, some spread of the new technologies has been seen to occur via the organic process identified by the Practice Change Group in other agricultural sectors.

The AWRI has also worked closely with other research providers and industry partners to identify practical and adoption-ready solutions which will drive uptake of research outputs by industry. A focus has also been placed on promotion of the outputs of this stream, in conjunction with AWRI researchers, including providing industry demonstrations, training and implementation assistance, where required.

6. Results and discussion:

Goals:

- Increase industry access to application-ready technologies that have the ability to add value and reduce costs during the grape and wine production process.
- Increase understanding of the key compositional and processing variables that impact on wine quality and consumer value.

A web-based tool to measure tannin, colour and other phenolic parameters in red grapes, fermentations and wine

Several outputs of this stream relate to tools which allow for rapid and simultaneous measurement of a number of variables which can be objectively related to the quality assessment of grapes and wines. This includes a web-based tool developed to measure tannin, colour and other phenolic parameters in red grapes, fermentations, and wine.

To many winemakers and those in the wine trade, phenolic compounds are the things which define the intrinsic value of red wines, being a major influence on their colour and textural properties. Until now, however, they have been difficult to measure, and so largely overlooked. The technology to measure phenolic compounds is now widely available. When combined with methods for the more rapid analysis of grape compositional variables (also developed under this stream), there is the potential to substantially increase the understanding of the relationships between grape and wine composition. These tools inform the way grapes are selected and paid for, and allow more objective target specifications to be set.

In 2005, the AWRI conducted a review of tannin research, which concluded that the available analytical methods were too complicated, not specific or not suitable for wine tannins and that there was no simple method available to aid industry trials and decision making. The AWRI responded by developing the methyl cellulose precipitable (MCP) tannin assay for red wines, which was a major simplification of previous methods.

However, an industry survey conducted under this stream in 2008 revealed that while the majority of respondents wished to be able to measure tannin and other variables related to phenolics, they wanted faster and simpler analytical methods. Consequently a rapid spectral (UV-Vis) method for predicting colour, tannin and phenolics in red wines and in fermentations was developed, which was correlated with the MCP assay (Dambergs et al. 2011a, 2012a). That capability was delivered to industry through a web interface called the AWRI Tannin Portal, to provide a simple measurement tool that could be employed by wine producers using their own equipment (Dambergs et al. 2011b, 2012b).

In response to Tannin Portal user feedback, and as a result of industry trials which identified links between grape colour and tannin and wine colour, the Tannin Portal was extended with the inclusion of a number of additional variables of wine phenolic composition, which was then further extended to allow for the analysis of grapes as well as wines. The combined platform was renamed the WineCloud.

WineCloud can be further extended as new methods become available. It provides industry with a simple and rapid method to gather data from wine processing and targeted winemaking trials, improving decision making to achieve specific target attributes for wines. For instance, it has been used by producers to obtain objective process data to assess the impact of winemaking variables such as maceration technique and yeast type, and has provided some early insights into links between grape and wine tannins.

The platform also contains a suite of tools that allow simple graphical representation of data such as grape maturity trends; attribute profile charts; and fermentation trajectory plots, as well as an extensive database of grape and wine data, against which users are able to benchmark specific attributes in their own grapes and wines by a combination of vintage, variety, and region.

Spectral fingerprinting; a technique to measure grape and wine style objectively

A technology developed by this stream is that of ‘spectral fingerprinting’ which, when fully developed for a particular application, allows wine, and potentially grape style, to be ‘measured’ objectively. Spectral fingerprinting is the use of spectral data to define a large number of compositional variables in a sample simultaneously, rather than using individual tests to measure individual parameters. This concept has potentially profound implications for the way grapes are grown, selected and paid for and for how wines are produced; the spectral fingerprint can be considered an objective and holistic target of a style of wine a producer wishes to make. The concept could, in theory, also be applied to grapes in order to select those which best allowed the desired wine style to be produced, and to define objective target specifications against which grapes can be grown. (Dambergs et al. 2002; Cozzolino et al. 2010b; Cozzolino and Dambergs, 2010a).

The PinotG Style Spectrum

The first fully developed example of spectral fingerprinting is a wine labelling device called the PinotG Style Spectrum, which enables consumers to be aware of the style of the wine in the bottle before they purchase or consume it.

The Pinot Grigio/Pinot Gris (PinotG) grape variety is made into two classic styles in Europe, with the Italian Grigio generally being a crisp and delicate wine, and the French Gris being luscious and more full-bodied. Australian wine producers are making both of these classic styles, and a ‘spectrum’ of other styles, all displaying various degrees of the traditional styles in wines with the same name. The AWRI was approached by a number of wine producers regarding market confusion surrounding the use of the grape variety synonyms Pinot Grigio and Pinot Gris, and the styles of wines being bottled using those terms. This was of particular concern because the amount of the variety planted had increased rapidly, and they feared that the market confusion might have a negative impact on wine sales.

Extensive sensory evaluation was performed in collaboration with sensory panels comprising staff from the AWRI and many Australian PinotG winemakers. It was established that a spectrum of styles did exist in Australian PinotG wines between the extremes of 'crisp' and 'luscious', and the panels were able to reliably rate the style of individual wines on such a conceptual scale.

Based on this, the AWRI developed a rapid spectral measurement technique to predict a sensory panel's assessment of the style of PinotG wines, with a view to communicating wine style to the market via the wine label (Robinson et al. 2011). This involved extensive industry collaboration and an industry working group was formed comprising a business consultant and representatives of leading PinotG wine producers. Wine Australia has also been a major collaborator to ensure that work takes regulatory and compliance requirements into account. The PinotG Style Spectrum labeling device developed is shown below (Figure 1). Proof-of-principle studies conducted in collaboration with leading wine producers, demonstrated that the style of Chardonnay wines could also be 'measured' in a similar way, using the 'anchor terms' 'fine' and 'full' rather than 'crisp' and 'luscious'.

Figure 1: PinotG Style Spectrum graphic

BevScan – A non-invasive spectroscopic screening device

The AWRI receives a significant number of enquiries each year from wine producers who have issues with the variability of their bottled products. These issues can be due to inadequate storage conditions, variable closure performance, problems during transport and distribution and variability introduced at bottling. Potentially, a proportion of bottles are unsalable due to the consequences of low sulfur dioxide (SO_2) concentrations, such as elevated colour development or oxidative sensory characteristics, and variability caused by other factors such as microbial contamination is also encountered.

Typically, when such problems exist, bottles of the affected wine are subjected to sensory assessment and/or chemical analysis. While this approach makes it fairly simple to identify a variability problem such as oxidation, producers are still left with the difficult task of sorting the acceptable bottles from the unacceptable. In most cases, the expense of opening, assessing and re-sealing all bottles cannot be justified.

BevScan is an in-bottle spectrophotometer, developed under this stream in conjunction with Jeffress Engineering and the software company Camo, which can be used to identify spectral differences between bottles of wine non-destructively. Using Vis-NIR spectroscopy, matrix differences in wines can be identified, categorised and quantified rapidly (Cozzolino et al. 2007). The instrument is applied for the analysis of unopened bottles of wines which appear to exhibit bottle-to-bottle variability during storage and distribution.

A number of viable practical applications of the BevScan technology have been demonstrated, including analysis of wine differences due to closure performance (oxygen transmission rate), irregular storage and/or shipping temperature, identification of sparkling wines with variable CO_2 content and monitoring changes caused by storage temperature.

In one example, a spectral classification model was built using samples of a commercial red wine that were exhibiting sporadic patterns of oxidation during storage. This calibration model was then used to screen approximately 700 cases of wine and identify those bottles that had acceptable development characteristics (Group A in Figure 2), allowing the mobilisation of stock for overseas markets (Scrimgeour et al. 2012).

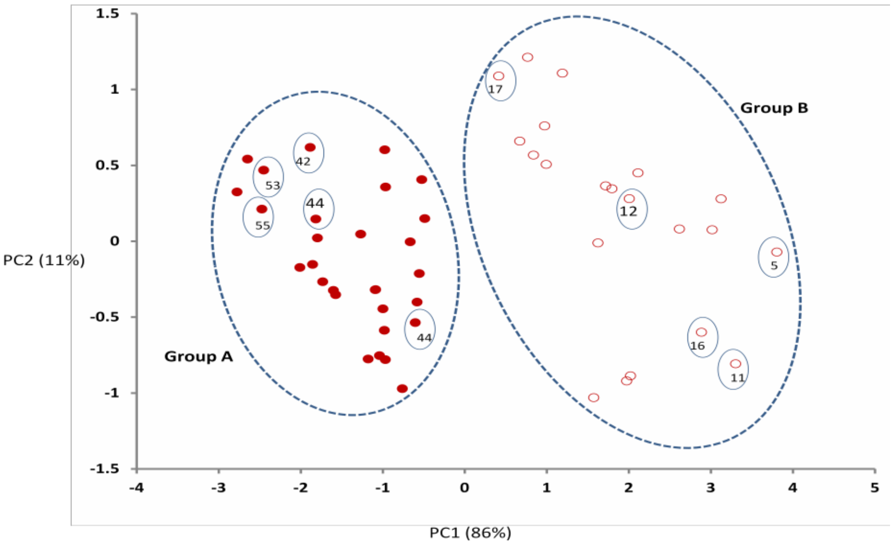

Figure 2: Principal component analysis (PCA) plot showing clustering of acceptable wine samples (Group A) and unacceptable wine samples (Group B). Values indicated relate to the level of free sulfur dioxide (SO_2) measured in randomly selected samples.

Goal:

- Increase access to rapid analytical and other ‘smart’ technologies to assist in improved decision making.

Application of rapid spectral technologies to the analysis of sugar and colour maturity levels in grape homogenates

The Australian wine industry has a clear need for rapid methods for measuring grape composition in order: to determine optimum harvest dates; to identify areas in the vineyard with similar composition; and for the assessment of grape quality for appropriate payment. In order to analyse large numbers of samples, potentially hundreds per day as might occur at a commercial harvest receival weighbridge, spectroscopic methods have been employed in the last decade by some of the large wine producers for grape colour analysis as an indicator of grape quality.

The direct cost of spectroscopic analyses is much lower than traditional ‘wet chemistry’ methods, due to the absence of the need for reagents and less time required to conduct the analysis. However, the initial cost of buying instruments, such as the FOSS6500, which can be used for grape colour assessment, has been too high for medium and small-sized wineries.

However, with a new generation of smaller and cheaper instruments now available, that situation is changing. Under this stream, a Bruker Alpha Mid-IR instrument has been used to develop models for simultaneous measurement of a number of grape composition parameters. Robust calibrations have been developed for total soluble solids (TSS), total anthocyanins, pH, TA, and dry matter in grape homogenates. The initial calibration models included data for Shiraz, Cabernet Sauvignon and Merlot, from grapes sourced in South Australia during two vintages (2010-2011). Collaboration with wineries in the Riverina region (NSW) in 2013 provided a significant amount of additional data; more varieties were included, and the concentration range of the calibration was extended (see Figure 3).

These rapid measurements can replace the expensive and time consuming traditional laboratory methods and could ultimately be extended to measurements using hand-held devices during grape berry ripening and at harvest.

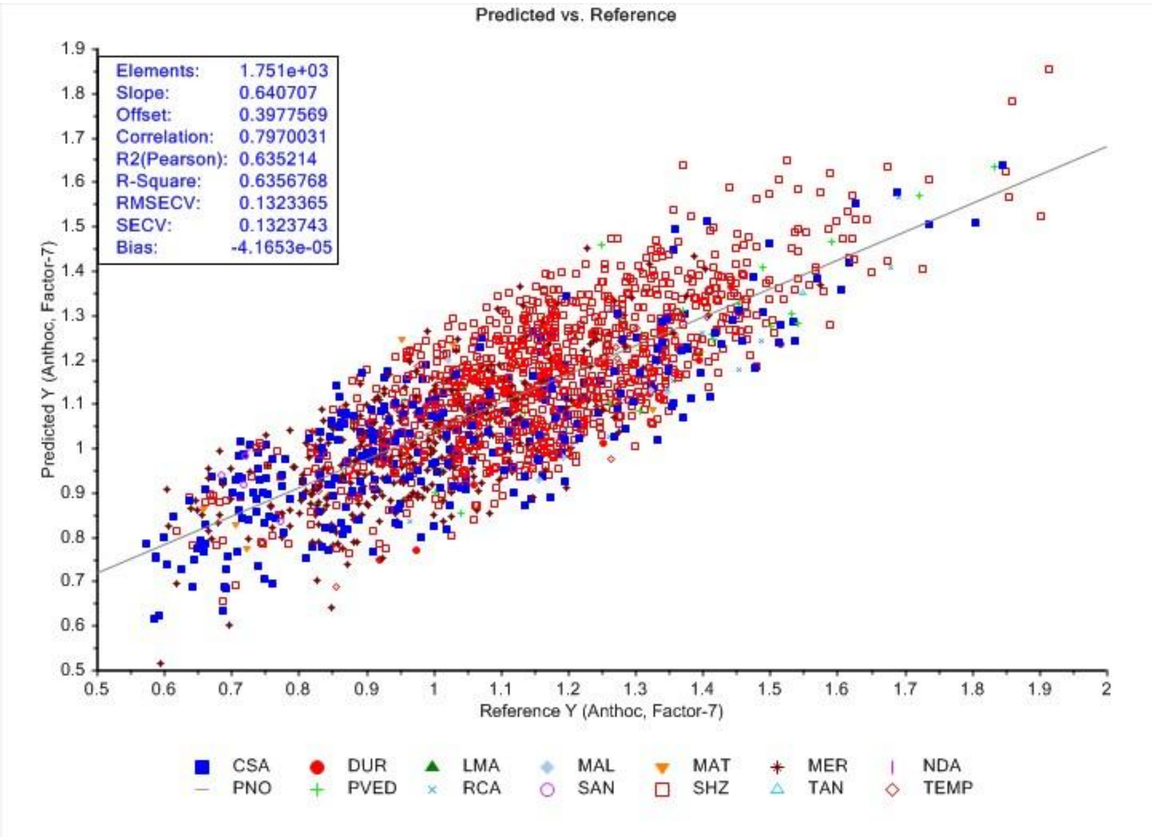

Figure 3: Correlation of anthocyanin values measured using Modified Somers reference method (x-axis) against values predicted using Bruker Alpha Mid-IR spectral method (y-axis).
KEY: CSA – Cabernet Sauvignon; DUR – Durif; LMA - Lambrusco Maestri; MAL – Malbec; MAT – Mataro; MER – Merlot; NDA – Nero D’Avola; PNO – Pinot Noir; PVED – Petit Verdot; RCA – Ruby Cabernet; SAN – Sangiovese; SHZ – Shiraz; TAN – Tannat; TEMP – Tempranillo.

The AWRI Ferment Simulator - a tool which models fermentation kinetics to predict fermentation performance

Winemakers recognise that fermentation is a critical area where quality can be enhanced or lost quickly and suddenly. Therefore there is a demand for tools which enhance winemakers' ability to monitor their fermentations and to give greater control and more confidence in the final wine outcome.

Current fermentation management practices place huge demands on winery resources, ranging from daily sample collection, laboratory analysis and winemaker tastings to infrastructure constraints such as equipment availability, energy and water use and refrigeration capacity. Process efficiency is further impacted when stuck or sluggish fermentations occur, with additional resources and logistical management being required as a result.

The ability to reliably and accurately monitor and control fermentation in real-time is crucial to minimising operating costs whilst realising maximum wine quality potential (Muhlack 2008). That need has been recognised by the development of the AWRI Ferment Simulator: an Excel-based tool designed to provide wine producers with the capability to monitor and predict wine fermentation performance.

The simulator uses a complex set of calculation algorithms to predict ferment trajectory in relation to various operating conditions, including temperature, yeast strain, wine type, nutrient levels, agitation regime and fermenter size (Muhlack 2012a, b). The system was developed using commercial-scale fermentation data sourced from multiple sites over several vintages, and provides automated early warning of fermentations which are likely to be extended, or to stick, once as few as four data points related to the fermentation's progress are available in its early stages. The simulator also provides the means for real-time control in order to achieve quantified compositional targets, such as residual sugar, colour, and tannin concentrations, and allows for refrigeration demand to be calculated for an entire tank-farm for several days in advance, according to forecast weather. That feature allows winemakers to plan their refrigeration use in order to avoid exceeding their contracted electricity supply on very hot days, thus avoiding punitive electricity tariffs (Figure 4).

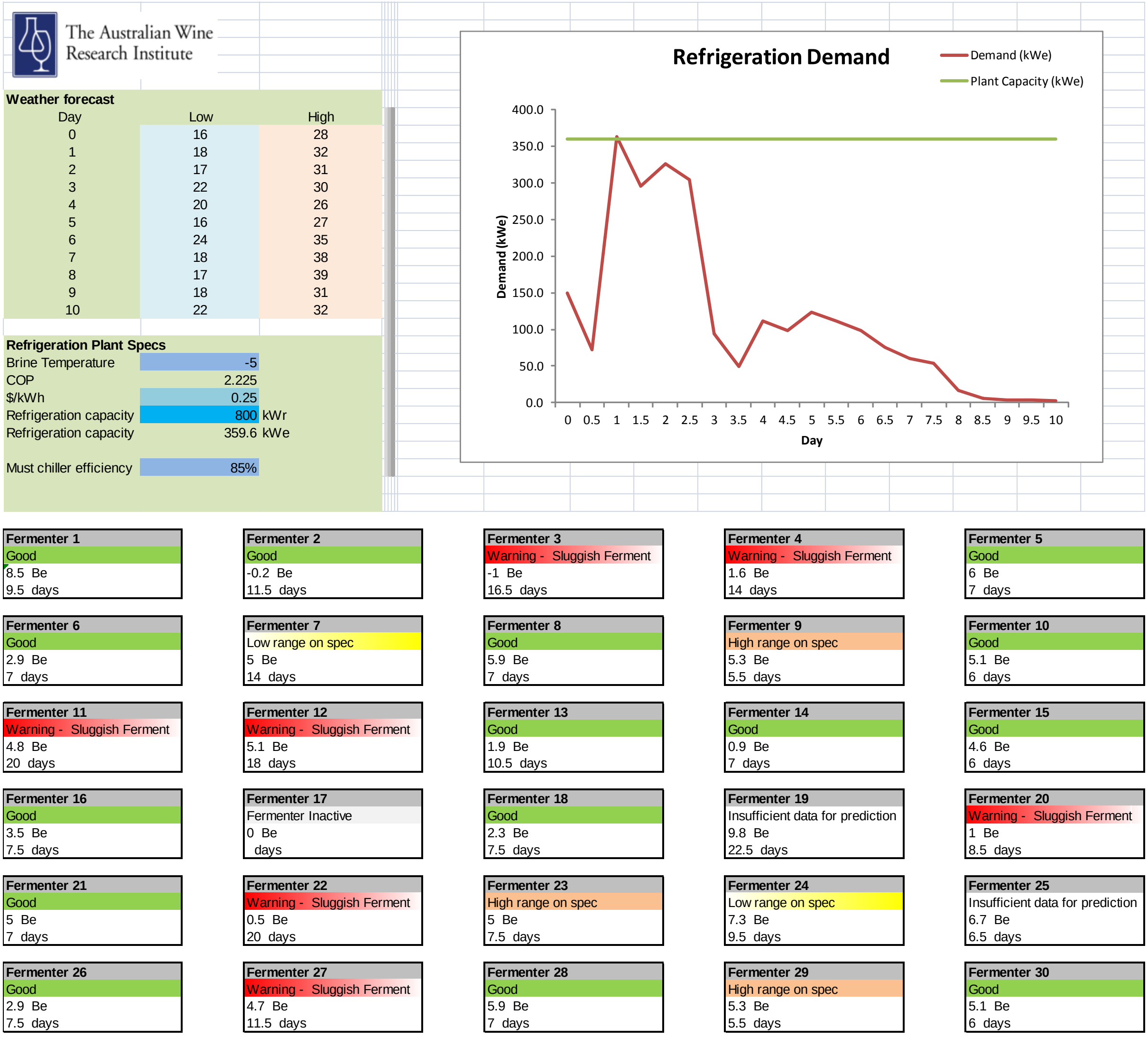

Figure 4: An example ferment status screen for a typical commercial tank farm, including upcoming weather forecast and predicted consequential impact on refrigeration demand

Rapid measurement of yeast assimilable nitrogen (YAN), to improve wine quality and fermentation management

Spectroscopic methods can be used for rapid prediction of a range of grape and wine composition parameters, and a number of methods have been developed under this stream using affordable, 'off-the-shelf' spectroscopy instruments (Shah et al. 2010, Cynkar and Wilkes 2011). One specific application developed using a Bruker Alpha Mid-IR instrument, has focused on the simultaneous analysis of pH, titratable acidity (TA), sugar content (Brix) and yeast assimilable nitrogen (YAN) in juices. Prototype calibrations were developed (see Figure 5 below) and, following establishment of the AWRI Riverina Node, the project was extended into the Riverina for further development and validation across multiple vintages. More recently, the work has been extended further to include Tasmania and the Hunter Valley via the AWRI nodes in those regions, although industry feedback indicates that insufficient YAN is not considered a problem in Tasmania.

This rapid method clearly shows the value of this type of instrument for juice monitoring, providing rapid feedback on nutrient status to winemakers. Measuring YAN concentrations prior to fermentation is very important as insufficient YAN (<160 mg/L) in the juice/must can result in sluggish or stuck fermentations and the production of hydrogen sulfide. Conversely, elevated levels of YAN (>350 mg/L) can lead to the formation of undesirable flavour and aroma characteristics in the resultant wine. However, few producers measure YAN on a regular basis because analysis requires a relatively time consuming two-stage wet chemistry assay. Rather, many producers rely on 'preventative' routine additions of di-ammonium phosphate (DAP) to all juices, which pose the risk of elevating the YAN concentration to undesirable levels.

Data collected on YAN concentrations in juices across multiple vintages has shown that approximately 60% of samples did not require a DAP adjustment, even though many producers make routine standardised additions to every fruit parcel without regard to actual YAN concentrations. This finding further emphasises the value in providing a means of rapid juice analysis; avoiding the cost of unnecessary DAP additions, while optimising wine quality by directing additions only when and where they are needed.

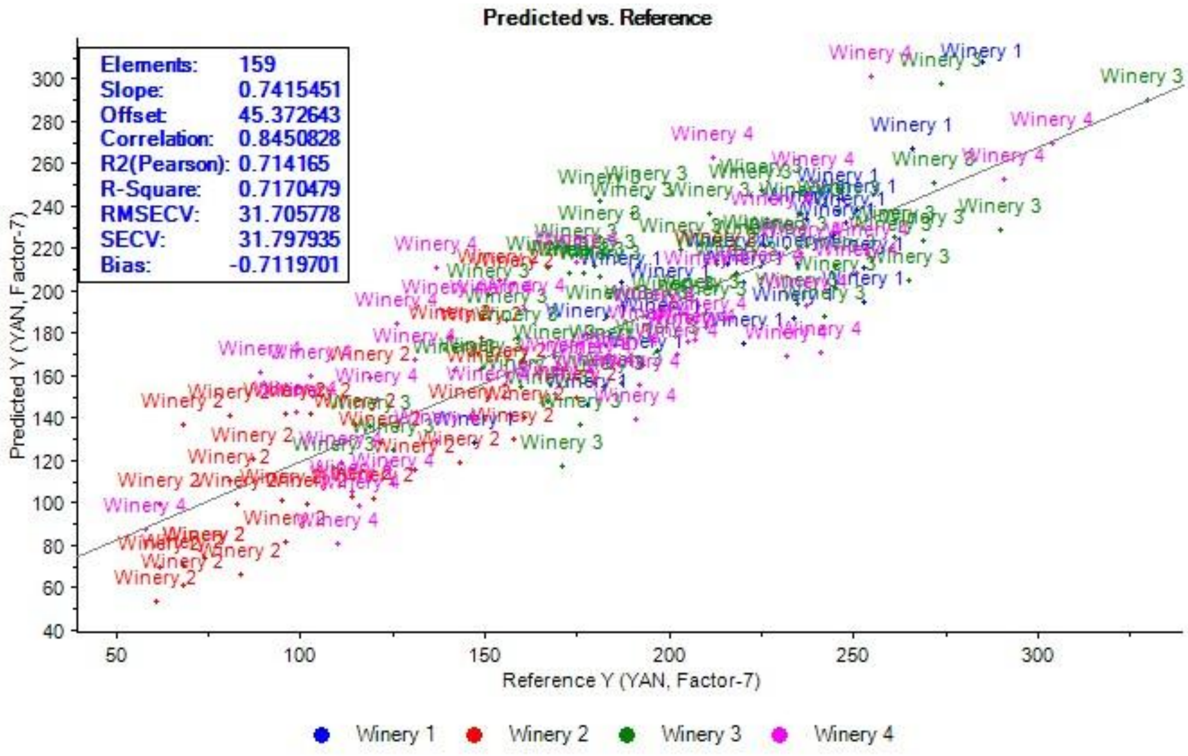

Figure 5: Correlation of yeast assimilable nitrogen (YAN) values measured using enzymatic reference method (x-axis) against values predicted using Bruker Alpha Mid-IR spectral method (y-axis). Calibration model includes data from four individual wineries, covering multiple vintages.

Goals:

- Improve industry access to process engineering and environmental-impact reduction expertise.
- Help to reduce the environmental impact and improve sustainability of the wine industry, by identifying potential opportunities for the application of environmental engineering principles to grape and wine processing operations.

Proctase - a viable alternative to bentonite

Bentonite clay is used as a fining agent in the production of white, sparkling and rose wines in order to remove proteins that could otherwise form unsightly haze after the wine is bottled. While it is a very effective way to remove those proteins, the bentonite fining step is cumbersome, tends to tie up tank time, causes volume and quality loss and presents waste disposal challenges. Bentonite is also very abrasive, causing accelerated wear on winery equipment such as pumps and centrifuges. Although in-line dosing of bentonite is currently used by several of Australia’s largest wine producers due to its lower cost and efficacy on a large-scale, most Australian wineries do not have the necessary infrastructure to consider this process modification.

Through Stream 2.2, the AWRI has sought alternatives for preventing haze formation, reducing the cost of bentonite treatment and/or removing the proteins via means other than bentonite. The research has focussed on two areas: understanding the mechanism of haze formation and the proteins responsible; and using that knowledge to find solutions to the problem. Proctase, a commercially available mixture of two acidic proteases produced from Aspergillus niger (EC no. 3.4.23.18 and 3.4.23.19), was identified as a potential bentonite alternative. Bench-scale trials demonstrated that at elevated temperatures it was effective at removing the proteins responsible for haze formation.

Field trials coordinated in Adelaide and the Riverina Node, were conducted with three industry partners in the Riverina and South Australia during the 2011 and 2012 vintages. These trials assessed the potential of Proctase to remove heat unstable proteins from white juices, (Robinson et al. 2012, Marangon et al. 2012b). The trials demonstrated that a combination of flash pasteurisation treatment of white juice at 75^{o}C in the presence of Proctase, was effective at removing the haze-forming proteins (Chitinases), resulting in a protein stable wine (Figure 6).

A review of the regulatory environment surrounding the use of acidic protease enzymes in winemaking has highlighted that the enzymes present in the Proctase formulation are listed synonymously (carboxyl proteinase or EC no. 3.4.23.6) as approved winemaking additives in the current Food Standards Code (1.3.3). The AWRI is currently progressing formal recognition of this from Food Standards Australia and New Zealand (FSANZ), through an update to the Code.

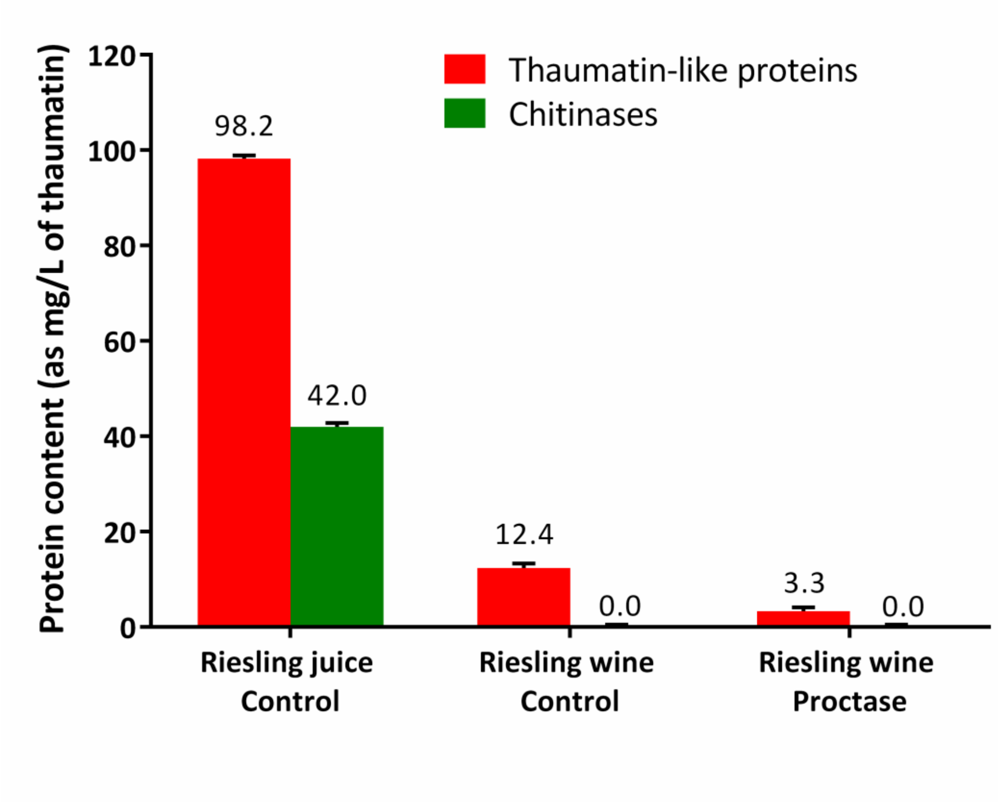

Figure 6: Average levels of Thaumatin-like proteins and Chitinases in Riesling juice and wine treated with bentonite (Control) and Proctase. Error bars indicate standard deviation across three replicates.

Goal:

- Demonstrate through specific studies the benefits to the environment of adoption of alternative 'green' technologies.

Under this stream, work was completed on the assessment of the use of grape stalks and marc as a source of renewable energy. That analysis rules out the use of these materials for the production of bio-fuel, but has delivered a favourable assessment of their use to generate electricity. This work has provided objective data on which decisions to invest in electricity-generating equipment can be based, and at least one major tender for the construction of such a plant has been released during the life of this stream. More information on this work is provided under Stream 4.4.

Goals:

- Understand the critical factors, cultural and environmental, contributing to the relative propensity of red wines to undergo Brettanomyces-related spoilage.
- Develop effective control mechanisms, where possible specific to strain and wine composition differences, in order to minimise collateral negative effects on wine quality and style.
- Define the differences between sensory characteristics of wines that are and those that are not spoilt by Brettanomyces under Australian conditions, and identify the important changes that occur in the chemical composition of wines when they undergo spoilage.
- Provide tools and training to the industry enabling it to estimate and eliminate the risk of Brettanomyces -related spoilage based upon defined wine or strain properties.

Characterisation and control of Brettanomyces spoilage yeast

Four-ethylphenol (4-EP) and 4-ethylguaiacol (4-EG) are products of the metabolism of *Brettanomyces* yeast in wine. 4-EP is responsible for the 'band-aid' and 'medicinal' aroma found in some red wines when present at concentrations above the sensory threshold and is generally regarded as detrimental to wine quality even at concentrations below the sensory recognition threshold. A survey by the AWRI of the incidence and levels of 4-EP in commercial Australian wines conducted between 1996 and 2005 (Figure 7) showed that 4-EP levels steadily fell during this period, due to more proactive management by winemakers instigating management practices advocated by the AWRI. However, *Brettanomyces* remained a threat to wine quality in Australia.

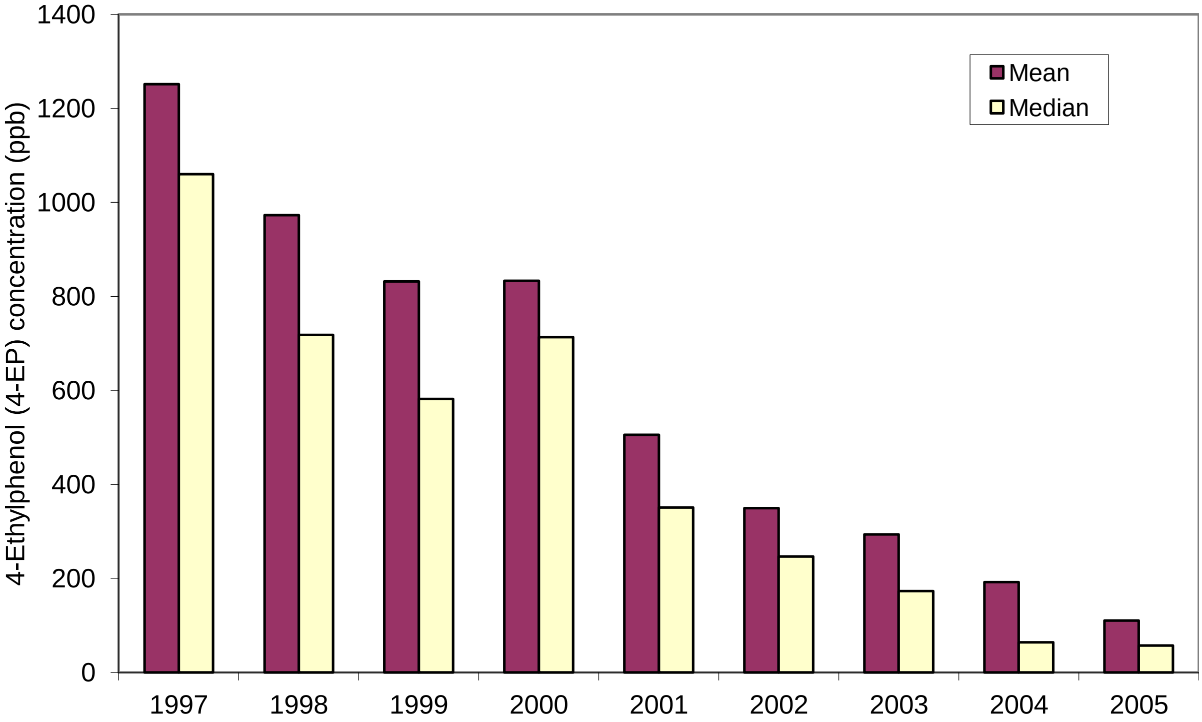

Figure 7: Mean and median concentration of 4-ethylphenol (4-EP) measured in randomly selected Australian wines between 1997 and 2005.

Through this stream, genetic fingerprints were generated for 244 *Brettanomyces* isolates from red wine made in 31 winemaking regions of Australia. Results indicated that there were eight different strains amongst the isolates, and three of these were commonly found across multiple winemaking regions. Analysis of ribosomal DNA sequences provided further evidence of three major groups, while the combined data suggested there were significant genetic differences between the most commonly isolated *Brettanomyces* strain and the reference strain (Henschke et al. 2007; Curtin et al. 2007).

Further analysis of the isolates demonstrated a wide range of tolerances to sulfite. The most tolerant strain, which comprised 85% of all Australian isolates, was able to grow in the presence of sulfite concentrations five times higher than the strains most sensitive to sulfite. This potentially explains its widespread occurrence in Australian wineries (Curtin et al. 2012).

A significant amount of sensory evaluation work was undertaken, including two consumer studies which examined the perception of 'Brett' character in different wine styles (i.e. 'oaky' or 'green' wines), arising from different ratios of 4-EP and 4-EG (Curtin et al. 2008). This provided an improved understanding of how 'Brett' is perceived differently according to the wine matrix and insight into why some wines are considered to be more or less 'Bretty' than would be expected, based upon the 4-EP concentration alone.

Further regional survey work suggested that the likelihood of encountering commercially available 'Bretty' wine was very low with wines from the 2005 vintage onwards, although some regional differences were identified. This survey activity was continued in 2009 with a smaller sample set, in order to ensure that Australian producers were alerted to any trends towards an increased incidence of *Brettanomyces* spoilage

Outcomes delivered through this stream relating to *Brettanomyces* have been communicated through a variety of conferences and regional workshops. Further work on genome sequencing of the industry-isolated strains is reported under Stream 2.1.

7. Outcome and Conclusion

The key outcomes for the Australian wine industry delivered through this stream for each output produced are as follows:

Tools which improve process measurement and control

The WineCloud, a web-based tool to measure tannin, colour and other phenolic parameters in red grapes, fermentations and wine

The WineCloud gives the Australian wine sector the ability to access and generate high-value compositional data related to tannin and phenolic profiles, using their own laboratory equipment. By combining sophisticated calculation algorithms and a user-friendly web-interface, grape and wine producers are able to measure and control variables which, for many winemakers, govern the intrinsic value of red wines.

This innovative web-based system is a major advancement in both processing control and grape and wine science. The tool allows for better prediction and targeting of grape composition at harvest, and more objective targeting of wine styles in real-time during fermentation, blending, and ageing, in accordance with consumer preferences. It is also a high-value tool for supporting research trials, which allows data for a large range of variables to be generated quickly and cheaply. Additionally, the platform provides a powerful benchmarking function, which allows comparison of the phenolic composition of grapes and wines, by vintage, variety, and region.

Application of rapid spectral technologies to the rapid analysis of sugar and colour maturity levels in grape homogenates, and yeast assimilable nitrogen (YAN) and other compositional variables in juices and during fermentation

A range of methods have been developed which allow producers to measure a range of important compositional variables in grapes, juices and wines simultaneously, quickly, accurately and in real-time. It has previously not been feasible for most wineries to conduct such analysis so readily, or to collect such large volumes of data that these methods allow. The implications of this capability are that important relationships between grape and wine composition will be elucidated allowing the full value of grapes to be realised, and for more objective targets of wine style to be set and achieved during winemaking.

The AWRI Ferment Simulator - a tool which models fermentation kinetics to predict fermentation performance

The Ferment Simulator is one of a number of tools developed by this stream, which producers can access to improve processing efficiency. The Ferment Simulator enables winemakers to optimise fermentation performance to maximise wine quality, while also providing early prediction of where problems will arise. It also allows better management of refrigeration, the major use of power in a winery, thus reducing electricity use and the price paid for electricity if punitive tariffs are avoided.

Methods which increase processing efficiency and reduce processing costs

Proctase - a viable alternative to bentonite

Proctase provides an effective enzymatic protein stabilisation method which is a commercially viable alternative to bentonite. The traditional bentonite batch-fining step is cumbersome, tends to tie up tank time, causes volume and quality loss and presents waste disposal challenges. Bentonite is also very abrasive, causing accelerated ware to winery equipment such as pumps and centrifuges. Proctase significantly reduces process costs, in comparison with batch dosing of bentonite, and environmental impact, and its widespread introduction would represent the most fundamental change in white wine processing for several decades.

Characterisation and control of Brettanomyces spoilage yeast

The work conducted under this steam on *Brettanomyces* spoilage yeast has provided evidence that *Brettanomyces* strains isolated from Australian wine have genetically-based differences in their sulfite tolerance. That knowledge allows the development of rapid genetic-based testing methods for *Brettanomyces* contamination during wine processing. Such methods will further reduce the resources currently required to monitor and control *Brettanomyces* in wineries and provide early warning of the emergence of mutated strains with increased sulfite tolerance.

Development and application of the concept of spectral fingerprinting; a technique to objectively measure grape and wine style

The PinotG Style Spectrum – A labeling device which informs consumers of the style of wine in the bottle

The 'spectral fingerprinting' technology developed by this stream, has potentially profound implications for the way grapes are grown, selected and paid for, and for how wines are produced. When fully developed for a particular application, it allows wine, or potentially grape style, to be 'measured'. The spectral fingerprint can be considered an objective and holistic target of a style of wine a producer wishes to make. The concept could, in theory, also be applied to grapes in order to select those which best allowed the desired wine style to be produced, and to define objective target specifications against which grapes can be grown. The concept of spectral fingerprinting has also been demonstrated in assessing wine authenticity and integrity, which are likely to become bigger issues for the wine industry in the future. PinotG Style Spectrum enables consumers to be aware of the style of the wine in the bottle before they purchase or consume it, based on a spectral fingerprint of the wine's style, and allows wine producers to create a point of difference in the marketplace. The extension of the principle has been demonstrated for Chardonnay wine style, and might also be applicable for objective definition of regional 'typicity'.

BevScan – a non-invasive spectroscopic screening device

BevScan is an in-bottle spectrophotometer which uses Vis-NIR wavelengths to identify and quantify matrix or 'fingerprint' differences between bottles of wine, non-destructively. As a bench-top instrument, BevScan has several applications in the wine industry; but the full-value of this technology will be realised when it is applied on-line or in-line, allowing real-time fingerprinting analysis during grape and wine processing and during bottling.

8. Recommendations

This stream has successfully generated an extensive suite of outcomes which have been made available to the grape and wine sector as knowledge, tools, or methods. For some, development is complete and, for others, further industry evaluation and adaption will be required before a fully evolved product is available for widespread industry adoption.

To date, the extent of adoption of some of the outcomes has been moderate, and adoption has mainly occurred with medium and large wine producers which have the internal capability and resources to utilise the outcomes effectively, as well as the greatest need to reduce the costs and complexity of their processing.

Additionally, many of the technologies developed by this stream are relatively complex and represent a paradigm shift in the way grapes and wines are processed and analysed; consequently a hands-on approach to fostering adoption has been necessary.

In order to increase adoption by industry and maximise the return on the investment made to date, the following steps are recommended:

- That outcomes are made more readily available to industry for further evaluation and adoption:
    - Facilitation of access to technology outcomes such as the WineCloud, the Ferment Simulator and the rapid YAN method, should be extended through regional associations, (addressed in Project 4.3.1 of the AWRI's R,D&E plan 2013-2018).

- That investment is made to further develop the outcomes of this stream into on-line tools where appropriate:
    - Many of the outputs are suited to web-based application, the efficacy of which has been demonstrated with the phenolic analyses made available to industry via the WineCloud. It is recommended that the WineCloud be extended to incorporate the fermentation simulation model described here, as well as tools which allow users to conduct advanced statistical benchmarking of their own data, against the vast library of data which is held in the WineCloud, (to be addressed in Project 4.1.5 of the AWRI's R,D&E plan 2013-2018).
    - Potential also exists to extend the concept of modelling beyond fermentation simulation, to other parts of the grape and wine production process, and to incorporate such models into the WineCloud, (to be addressed in Project 4.1.5 of the AWRI's R,D&E plan 2013-2018).

- That investment is made in complementary technologies which would add greater value to the outcomes of this stream:
    - To be of maximum value, models such as the fermentation simulator requires real-time data to be available on which to base predictions and assessments of the conditions of a wine, compared to known standards or specifications. An obvious opportunity therefore exists to invest in the development and adoption of process analytical technologies which have been tailored to the requirements of the grape and wine sector, in order to gather such data in an automated way, and feed it into such models in real time, (to be addressed in Project 3.3.5 of the AWRI's R,D&E plan 2013-2018).

- That investment is made in extending the concept of spectral fingerprinting:
    - The spectral fingerprinting concept potentially has great value beyond labeling wines made from Pinot Gris / Pinot Grigio. The concept could be applied during wine production and to the analysis of grapes, as well as to further labeling devices for other grape varieties, wine styles or the characterisation of regional typicality, (to be addressed in Project 3.3.5 of the AWRI's R,D&E plan 2013-2018).

- That further investment is made in the regional nodes network, particularly in their development and adoption functions.

- That the nature and value of the stream outcomes are extended to industry via:
    - continued communication on the benefits of adoption through AWRI road-shows and targeted workshops, (addressed in project portfolio 4.1 in AWRI's new R,D&E plan);continued development of focused case studies which showcase the practical use and benefits of adoption, in collaboration with industry partners, (to be addressed in Project 4.3.1 of the AWRI's R,D&E plan 2013-2018); and
    - the provision of support for industry partners in the generation of additional process knowledge through the application of these outcomes, so that the value of the benefits derived can be quantified and communicated to other potential users, (to be addressed in Projects 4.1.2 and 4.3.1 in the AWRI's R,D&E plan 2013-2018).

9. Budget reconciliation:

Financial Year	Receipts / Income ❶	Outgoings / Expenditure ❷
Year 1: 2006/2007	$1,005,826	$1,005,826
Year 2: 2007/2008	$1,168,579	$1,168,579
Year 3: 2008/2009	$1,223,156	$1,223,156
Year 4: 2009/2010	$1,487,300	$1,487,300
Year 5: 2010/2011	$1,200,309	$1,200,309
Year 6: 2011/2012	$1,145,928	$1,145,928
Year 7: 2012/2013	$938,235	$938,235
TOTAL	$8,169,333	$8,169,333

❶ Note that the GWRDC – AWRI Investment Agreement budget was established and approved at an aggregate level, with variances to budget (i.e. annual overspends and underspends) reported and considered at that same aggregate (i.e. whole of agreement) level. The receipts / income relating to a Stream for any year therefore equate to the outgoings / expenditure within that Stream for that year, as any variances between total Investment Agreement funding received and total funds expended were considered at the whole of Agreement rather than individual Stream level.

❷ Includes a pro-rated share of Theme 5 *Executive management and administration*.

I hereby certify that this statement is true and accurate.

Signature of duly authorised representative..

Chris Day	Group Manager – Corporate Services	29/11/2013
Name:	*Title:*	*Date:*

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