PEGRAS

NSSN
NSW Smart Sensing Network

HDPE Recycling

Increased recycling of plastics by sensing and treating label contamination

Final Report – December 2021

Cite report as:
Byrne, I., Dvorak, R., Florin, N., Hawkett, B., Jazbec, M., Lang, G., Li, S., McCallum, D., Madden, B., Nguyen, D., Peters, S., Shen, Y., Zhuo, S. (2021) HDPE Recycling: Increased recycling of plastics by sensing and treating label contamination. A CRC-P summary report prepared by the NSW Smart Sensing Network.

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Foreword

New South Wales intends to be at the global forefront of recycling and the circular economy.

The pressure on our environment and carbon cycle; the pointed impact of changes to global recycling which began in 2017; further exacerbated by the disruption to global supply chains by COVID-19, are all structural features demanding more innovation in our recycling sector.

Real actions that achieve real outcomes are required, and we are happy to say that this has been a project with immediate and sustainable impact. Many recycling processes are underpinned by better sorting and this fundamentally means better sensing. The NSW Smart Sensing Network is proud to have formed a team of collaborators including small and large business, and several participating universities, in first proposing, and then successfully delivering on, a great project that was supported by our federal counterparts as part of the Cooperative Research Centre Projects scheme.

The project essentially cracked the problem of what to do with label contamination on HDPE milk bottles, one of the biggest contributors to our waste streams, and supported this with demonstration of industrial scale-up and a holistic understanding of the material flows.

While the full impacts of the research will continue to filter down over time, we are already seeing adoption of the findings by the dairy industry and a willingness of partners to collaborate on future projects. There are firm indications the major MRFs and supermarket chains will use more innovative approaches as a result of this project. What we do know for sure is that there is no hiding from the willingness of our great minds and savvy businesses to innovate. No one can say "its too hard" or "it can't be done".

Prof Hugh Durrant-Whyte

NSW Chief Scientist and Engineer

January 2022

Executive Summary

This project has delivered solutions to the problem of label glue contamination that limits yields in the recycling of HDPE milk bottles. A new label and glue removal method was demonstrated; a test method for measuring the purity of HDPE flakes was optimised; a prototype scale-up test reactor was shown to be highly effective; and changes to the glue and label formulation were made that reduced the levels of contamination. An analysis of HDPE material flows through the economy showed future recycling scenarios in the Australian economy.

The project, with the full title *Increased recycling of plastics by sensing and treating label contamination* was undertaken under the auspices of the CRC-P Round 8 program and ran from May 2020 to August 2021. The documented value of the project including grant and in-kind contributes is just over $1.64 Million, though there is much additional time and effort from all stakeholders in the project that is not represented in that figure.

Crucial to the success of the project was the effective collaboration of the project partners.

PEGRAS Asia Pacific, the Lead Partner, is a technical solution consulting company based in NSW, who have longstanding, expansive and international knowledge of the print, packaging and recycling markets. They developed the initial proof of concept chemistry for glue removal, then designed the research program that has evolved into this CRC-P project, and provided leadership in chemical and process engineering.

Labelmakers is Australasia's largest and most innovative label supplier. They have, by some margin, the biggest market share in the supply of labels on supermarket items sold in Australia. They supplied materials and technical advice to other partners in the project and led the trails in new glue and label formulations.

The Institute for Sustainable Futures (ISF) is a transdisciplinary research and consulting organisation within the University of Technology, Sydney. ISF brings together expertise from a range of disciplines delivering practical and sustainable solutions for a socially, ecologically and economically safe and just word. They led the materials flow analysis and future scenario mapping of HDPE in the Australian economy.

The Laboratory of Process Modelling and Optimisation (ProMO) in the School of Chemical Engineering UNSW has an extensive history and reputation of direct engagement with the manufacturing industry. They created a mathematical model of the adhesive removal chemistry, driven on a supercomputer, enabling process parameter optimisation to be simulated. A prototype wash reactor was built to demonstrate the process at scale.

The Key Centre for Polymers and Colloids (KCPC), within the School of Chemistry at The University of Sydney has extensive history of contract and collaborative research with and for industry partners, as well as fundamental research in these areas of chemistry.

Real material processes were based on a major recycling facility in western Sydney, NSW.

The NSW Smart Sensing Network (NSSN) provided the initial networking to bring together the project team, drive the grant application and contracting, and continued with events, communications and media, governance and project management.

The project collaboration is a measurable success. The networking has allowed industry penetration into our universities, at the same time our universities have been able to direct their energies towards a real industry problem.

Key findings

This project solved a global problem of how to effectively remove the glue that adheres a label to a plastic milk bottle. This contamination problem has adversely impacted the industrial washing process of recycling food grade HDPE for the past 20 years. This enables the recycled content in HDPE to increase to 50% and beyond, and thus supports the transition to the circular economy for the 48,000 tonnes per annum of HDPE plastic used for fresh milk production in Australia.

Recycled HDPE can disengage the economics of polymer production from virgin HDPE which is derived from fossil fuels. The technology readiness level (TRL) of this process has moved from TRL 3: *Experimental proof of concept* to TRL 7: *Demonstration in operational environment*.

The fundamental chemistry aims of the project were met: The University of Sydney developed an analytical method which can efficiently quantify the glue content in plastics with a high degree of accuracy, an important step to enable benchmarking of improved processes. It was found that more than 50% of residue label adhesive remained in recycled HDPE after the pre-existing industrial washing processes. An improved washing processes was proposed, based on different solvent formulations and found to be very effective. Existing removal processes were effective but were affected by recontamination; this can be designed out.

Impact delamination technology delivered completely clean HDPE flakes without chemical washing. Impact delamination is a process of striking the contaminated HDPE flakes and label at high speed with sharp metal blades. The intellectual property behind this is patented.

Labelmakers trialled new label and glue formulations that University of Sydney testing found to significantly reduce the amount of contaminant adhesive.

UNSW developed an advanced mathematical model and used a supercomputer to describe the complex multiphase flows during the adhesive removal process and thus we can understand in detail the internal phenomena inside real industrial washing reactors.

The mathematical model was used to evaluate and test new designs and different operational scenarios extensively. Parameters variations to temperature, speed and materials composition were simulated using a supercomputer. Optimisation strategies were proposed that led to significant improvements in the washing efficiency.

A test rig was built that proved washing concepts, validated models, and aided scale-up from laboratory to industrial use. Collaboration between universities found the rig to be comparable to real industrial process at 2% of the production volume.

The project has identified that milk bottle recovery rate is far below the 70% recycling rate target. HDPE recycling is technologically mature, so this is of concern. Collection losses are the greatest barrier to better recycling with 59% lost to landfill. This could be addressed by a container deposit scheme (CDS) for milk bottles. Expansion of kerbside recycling services to all jurisdictions and better at-home consumer awareness and disposal practices is required.

Local recovery volumes of natural HDPE are sufficient to achieve the recycled content target of 20% for HDPE packaging, however adequate local demand must continue to grow. This includes removing the contaminants in recovered HDPE for food-grade applications. Using existing mechanical recycling systems, with advanced label and glue removal technology developed in this project, provides an opportunity to shift recoveries from industrial-grade (non-food-grade) recyclate to food-grade by addressing contamination.

Our findings and results have informed the development of the APCO and Dairy Australia roadmap for dairy packaging and have been précised in a public summary report.

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1 Overview

This project focused on increased re-use of HDPE (high density polyethylene) plastic.

Recycling companies today have problems in recycling HDPE because labels and their adhesives contaminate the mix. HDPE is a high-quality material and in demand for re-use but under 20% of used HDPE is currently recycled. Increasing re-use represents tens of millions of dollars of opportunity to Australian and industry, with global implications.

A partnership of technology, recycling and manufacturing companies collaborated to work with university experts in sensors, polymers, systems engineering and environmental policy to overcome this problem. The project aimed to identify novel ways to sense and treat residual contaminants on chips of HDPE in the recycling process. A technology review showed that this approach would be unique worldwide. Concepts and designs stemming from university research were translated for industrial processing of HDPE, and potentially adaptable to a broader range of plastics.

The project aimed to eliminate residual contaminates on recycled HDPE chips that limit the use of higher percentages in the re-manufacturing process. This project has the potential to divert hundreds of thousands of tonnes of waste plastic from landfill to remanufacturing processes.

Figure 1.1: It is scenes like this we would like to consign to history.

1.1 Aims

High level outcomes set at the outset of the CRC-P were:

- Improved sensing of HDPE and contaminate in the washing processes in recycling facilities for greater yields,
- Greater contaminant removal, via better polymer chemistry, further improving yields,
- Upscaling processes to better demonstrate readiness ready for adoption by recycling facilities,
- Broad stakeholder consensus for a future technology roadmap with an understanding of the whole-of-system impacts of the proposed technical solution, to support scale-up and achieve sector-wide deployment.

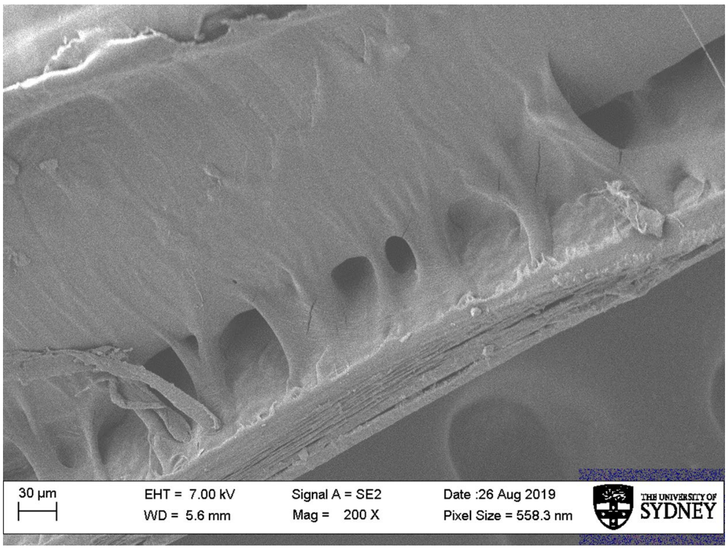

Figure 1.2: The fundamental HDPE recycling problem is clearly shown in this micrograph. The glue makes an extremely strong bond between the HDPE (thicker diagonal structure) and the composite label (thinner diagonal structure), making it very difficult to chemically or physically remove during the waste recycling process, and thus becoming a primary contaminant.

1.2 Intended benefits

The project aimed to deliver myriad benefits across industry and society, as follows:

- Increase yields of uncontaminated recycled HDPE (rHDPE). It is an expensive material, around $1850 per tonne for food grade rHDPE, so uncontaminated recycled rHDPE is a valuable commodity for recycling companies to sell. It is preferable to use recycled HDPE rather than virgin material,
- Because recycled HDPE is less exposed to fluctuations in the price of oil (the base product of HDPE), it is highly attractive to manufacturing companies. This is also an important step in reducing fossil fuel reliance and carbon reduction,
- Consumer goods companies that package products in rHDPE bottles will demonstrate their sustainability values to consumers and employees by increasing the proportion of recycled materials in their products,

- Australian companies in other areas of plastics manufacturing will be able to adapt this technology for their products,
- Industry human capability in waste reduction, manufacturing and recycling will be strengthened,
- Society and the broader economy as increased recycling of HDPE will reduce landfill. This work will be of great benefit to local councils, which collect materials for waste and recycling,
- The higher real and perceived value of waste HDPE will mean less gets into rivers and oceans,
- The technology developed in Australia has the potential be exported around the world,
- The data on entire supply chains and material flows will be learned through this project, with wide reaching potential.
- The usage of energy in the recycling process can be better understood, utilised and reduced,
- For research partners the benefits will include new knowledge, industry connections and stronger international reputations.

2 Participants and roles

2.1 PEGRAS Asia Pacific

PEGRAS Asia Pacific is a technical solution consulting company based in NSW. For several years they have been collaborating with the NSSN and a wide range of industry partners to solve real world problems.

With a network of consultants in Australia, Europe and Asia, PEGRAS has provided solutions for various companies, including Audi, BioOil, Continental, Siemens and TOYO.

Building on extensive background knowledge of print and packaging, their business focus includes developing solutions for the Circular Economy needs of plastic recycling. PEGRAS developed the initial proof of concept chemistry that has evolved into this CRC-P project and provides leadership in chemical and process engineering.

2.2 Labelmakers

Labelmakers started printing self-adhesive labels in 1987 and grew to become Australasia's largest and most innovative label supplier. Packaging has changed considerably over the last three decades and they have developed solutions that have responded to the changing needs of our customers. Self-adhesive labels are now just one of six core labelling products. Labelmakers supported this project as part of their commitment to exploring opportunities that expand business, grow their offerings to customers, remain competitive in a global market and look at ways to further reduce their carbon footprint.

2.3 University of Technology, Sydney: Institute for Sustainable Futures

The Institute for Sustainable Futures (ISF) is a transdisciplinary research and consulting organisation within the University of Technology, Sydney (UTS). ISF has been conducting project-based research across Australia and internationally since 1997 with a mission to create change towards a socially, ecologically and economically safe and just word. ISF brings together expertise from a diverse range of disciplines delivering practical and sustainable solutions.

Their research in plastics is focused on reducing the harmful social and environmental impacts of plastics and packaging through better approaches to design, re-use and recycling. We have helped industry and government to transition to more sustainable practices, following circular economy principles and taking a systemic, whole-of-supply chain approach. We draw on expertise in policy and regulatory analysis, product stewardship, stakeholder engagement, material flow analysis and social practices, as well as technical knowledge related to end-of-life management, chemistry and pollutant flows.

ISF played a major role in the NSW Government's decision to finally introduce container deposit legislation in 2017. More recently, our work has informed policy and strategy on waste management and resource recovery for packaging. For example, ISF's material flow analysis work and enduring partnership with APCO has informed strategy to meet the 2025 National

Packaging Targets. ISF work expands beyond the Australian context. For example, we have conducted research focussed on defining environmentally responsible trade in waste plastics and supporting transition to a circular plastic economy in India.

UTS ISF researchers have contributed to this project by providing a whole supply chain analysis from production, consumption, waste management and recycling to identify changes required for the transition to a circular economy. The importance of design, collection, sorting, and end markets for enabling circularity was evaluated, and specific opportunities and barriers for HDPE milk bottle system were explored. ISF used material flow analysis (MFA) and scenario modelling to quantify the impact of system changes, including the technical solution developed by the project team.

2.4 UNSW, ProMO Laboratory, School of Chemical Engineering

The Laboratory of Process Modelling and Optimisation (ProMO) led by Prof. Yansong Shen has an extensive history and reputation of direct engagement with the manufacturing industry. The ProMO Lab is equipped with world-leading numerical and experimental techniques for understanding and optimising complex processes, such as the recycling wash reactor processes under investigation.

Washing is the key step to separate labels from the bottles in HDPE milk bottle recycling. It required a full understanding in order to be optimised. However, the washing process was somewhat a 'black box' due constraints that hide the internal state of the reactor, including the closed environment, complex flows and high temperatures. Real plant tests would have been very expensive, risky, and extremely difficult to undertake given the very large volumes, access and other logistic impediments on the actual process plant.

Numerical simulations, supported by experiments, provide a cost-effective way for design, control, and optimisation of the washing process.

The UNSW project aimed to understand and optimise the washing reactor by means of computer modelling at industry-scale supported with laboratory experiments. The team at UNSW (Shen, Zhuo, Li) made a considerable contribution including developing a computer model of wash reactor and conducting several numerical experiments under a range of conditions for a range of parameters.

2.5 The University of Sydney, KCPC, School of Chemistry

The Key Centre for Polymers and Colloids (KCPC), within The University of Sydney (USyd) was established in 1999. KCPC undertakes contract and collaborative research with industry partners, as well as fundamental research and teaching in these areas. The group has a long track record of working with industrial partners to address material problems which may have significant impacts on the industrial landscape, including benefits to the environment. Prior collaborators include Dulux Australia, Dyno Nobel, Gelion, Syngenta, Sirtex Medial, Ferranova, Michigan Tech University and the USA Air Force.

In this project the KCPC investigated improved adhesive removal processes; they sought to develop a quantifiable, repeatable characterisation system for Labelmakers to measure changes to their adhesive and label formulations, moving beyond subjective human estimates; they analysed the phenomena of impact delamination as a glue and label removal method; they investigated the source of contamination in the industrial processes; and measured the effectiveness of the UNSW wash reactor.

2.6 NSW Smart Sensing Network

The NSW Smart Sensing Network (NSSN) is a consortium of leading universities across NSW and the ACT. Funded by the NSW Government through the Office of the Chief Scientist & Engineer, the NSSN bring together universities, government and industry to translate world-class research into innovative solutions to economic, environmental and social challenges

The NSSN served as a broker and activator in forming the project team. The Network coordinated the grant application and contracting, and continued throughout the life of the project with organising events, communications and media, governance and project management.

2.7 Personnel

The following people actively participated in the project:

Mr Ian Byrne, Consultant, PEGRAS Asia Pacific

Dr Nick Florin, Institute for Sustainable Futures, UTS

Prof Damian Giurco, Director, Institute for Sustainable Futures, UTS

A Prof Brian Hawkett, The Key Centre for Polymers and Colloids, The University of Sydney

Dr Melita Jazbec, Institute for Sustainable Futures, UTS

Mr Graeme Lang, Technical Manager, Labelmakers.

Dr Shuyue Li, Laboratory of Process Modelling and Optimisation (ProMO), UNSW

Dr Don McCallum, Theme Leader for Industrial Futures, NSW Smart Sensing Network

Dr Benjamin Madden, Institute for Sustainable Futures, UTS

Dr David Nguyen, The Key Centre for Polymers and Colloids, The University of Sydney

Dr Stephanus Peters, Consultant, PEGRAS Asia Pacific

Prof Yansong Shen, Laboratory of Process Modelling and Optimisation (ProMO), UNSW

Dr Yuting Zhuo, Laboratory of Process Modelling and Optimisation (ProMO), UNSW

Figure 2.1: Zoom Photo. From left to right: Don McCallum (NSSN); Stephanus Peters (PEGRAS); Nick Florin (UTS); Robert Dvorak; Yansong Shen (ProMo); Ian Byrne (PEGRAS); Duc Nguyen (KCPC); Brian Hawkett (KCPC) and Graeme Lang (Labelmakers). A project in the time of COVID-19!

3 Activities

3.1 Technical activities

3.1.1 Process engineering, modelling and scale-up

The ProMO lab activities commenced with a literature review, scoped out a program of works, and began to model the known industry wash process, including the sodium hydroxide (NaOH) wash process.

In the second quarter of the project they analysed the complex multiphase flow during the adhesive removal process to understand the details of internal phenomena inside the reactor. They were then able to apply the model and study the influence of different rotation speeds on the known industry wash process. This in turn allowed analyse of the influence of different rotation speeds on the known industry wash process to obtain optimal rotation speed. They designed the lab-scale test rig for the industry NaOH wash process.

Following from this they further developed the model to study the influence of different operating temperatures on the known industry wash process and analyse the influence of different operating temperatures on the known industry wash process and obtain optimal operating temperature. They then adapted the model to study the influence of different feeding ratios on the known industry wash process and obtain optimal feeding ratio.

In the final quarter of the project they made the experiment plans of the lab-scale test rig for the NaOH wash process. They tested a range of new designs and operational scenarios. Their work culminated in delivery of a commercial-scale production model and optimal operating conditions.

Figure 3.1: The test reactor. It represents about 2% of the throughput of the full scale plant.

3.1.3 Polymer chemistry, sensing and materials characterisation

Prior to the commencement of this project, KCPC had been exploring the use of impact delamination to cleanly remove the labels and glue from the surface of HDPE milk bottles. They have a patent covering their invention of this process. Impact delamination is a process that plagues the world of laminate use, such as in aircraft construction, laminated building products and car windscreens. In this earlier work they had sought to put this normally destructive phenomenon to good use.

KCPC primary role in the project was to develop a new characterisation technology which can help the industrial partner, Labelmakers, identify and improve their new glue technology. Before the project, there was no reliable method to quantify glue contaminant content in both commercial HDPE waste product and recycled materials. There is no standard analytical technique for glue. The best practice on factory floors is for the operator to use his or her hands to feel the glue tackiness of HDPE surface to accept and reject sample batches. This method is subjective, un-scientific and prone to errors. Development of a modern, scientific analytical technique for glue content in recycled plastic was our main objective. Once developed, one could then carry out analysis of current commercial samples to determine a benchmark level of glue. Labelmakers could then test their new glue on real plastic container samples which would then undergo recycling. By comparing values between new and old glues, Labelmakers could confirm whether their new formulation worked, or further improvements would be required.

A second aspect was to verify the effectiveness of KCPC glue removal technology. The new method involved a physical process called impact delamination and a new washing process. Using the new analytical technique, it was confirmed that the new glue removal technology offered superior performance over existing process currently used in the factory.

The third objective was to identify source of glue contamination during recycling process. Provided with the analytical procedure, KCPC helped the recycler to identify that their washing process was working, but the glue was recontaminating the HDPE after washing. This led to a recommendations for changes to procedures, leading to a cleaner output.

The final objective was to support the UNSW development of the prototype wash reactors. KCPC analysed the washed sample from the reactor so the UNSW team could confirm its effective operation.

There was a straightforward methodology to develop the glue characterisation technology. The first step was to understand the material in play, including chemical compositions of glue and other container plastics, and their physical interactions. This was followed by literature search to identify possible pathways to efficiently separate and quantify glue. No comparable process appears to have been documented, so it was necessary to make an original proposal. Based on experiences with other industrial projects, a feasible and accurate test method was devised, as described in section 4.1. The method was tested on known standards that confirmed its accuracy. It was then tested on prepared samples in which a range of percentages of glue were introduced on pristine HDPE samples. The method's accuracy was again confirmed, providing full confidence to apply the developed analytical technology to various samples including from Labelmakers and the recycling facility. Samples were analysed across a range of new and old glues and proving the data for Labelmakers to make glue formulation changes. The analytical method also confirmed that the impact delamination technology delivered as clean HDPE flakes as the washed flakes from the recycler.

3.1.4 Materials flow analysis

ISF started the project by conducting the review of the global policy and approaches supporting recycling of HDPE. They evaluated innovations aligned with circular economy principles, including standards, guidelines, policy, regulations, and industry-led approaches globally and in Australia. Based on this review they identified world best practice.

Considering the Australian milk bottle supply chain, they developed a supply chain model for the HDPE and rHDPE to undertake a material flow analysis (MFA) tracing flows from consumption to recovery at end of life. MFA modelling focused on current and projected milk bottles flows. ISF also developed and modelled future scenarios, that were tested with industry experts (see section 3.2.2), to quantify the impact of the proposed technical solution and identify other important interventions supporting high-value recovery pathways.

Finally, the ISF work highlighted the most impactful strategies to increase the recycling rates of HDPE recycling with the aim to meet the 2025 National Packaging Targets and transition to a circular economy.

3.1.5 Industry support

At all stages of the project the above research groups have been working closely with the industrial partners, PEGRAS, Labelmakers and the key recycling facility.

3.2 Events

3.2.1 Project Seminar

A key highlight of the project was a very successful seminar titled *Increased recycling of plastics by sensing and treating label contamination - Towards a Waste Free Future: Technology Readiness in Waste and Resource Recovery*, ran on the 27 April 2021.

The seminar was attended by over 80 people in person and a further 50 people online. The workshop was co-hosted with the Australian Academy of Technology and Engineering (ATSE), to coincide with the publication of their report into how technology can help Australian industry transition towards a circular economy.

This seminar looked at current research and development work being undertaken to tackle the challenges and to explore future directions.

The Keynote address was provided by Gabrielle Upton MP FAICD, Parliamentary Secretary to the NSW Premier and MC'd by Dr Susan Pond AM FTSE - NSSN Chair and part of the ATSE Working Group. Project talks were provided by PEGRAS and the participating universities.

Figure 3.2: Left) Minister Gabrielle Upton delivers the Keynote address. Right) The successful project was attributed to by strong collaborations between all the partners. From left to right: Ian Byrne (PEGRAS); Stephanus Peters (PEGRAS); Brian Hawkett (KCPC); Minh Lam (KCPC); Duc Nguyen (KCPC) and Vien Huynh (KCPC) in the event organised by NSSN.

A lively Q&A generated dozens of questions for the panel of Graeme Lang and Jess Walters of Labelmakers, Ad van Dijk from Bega Dairy, and Prof Thomas Maschmeyer of The University of Sydney.

3.2.2 Scenario mapping workshop

UTS ran a highly effective scenario mapping exercise on 22 June 2021. The project partners were joined by APCO, Bega, Nextek, Dairy Australia, AFGC, Fonterra and Food Plastics. The mapping exercise considered the current baseline, drivers for change, improving collection, high value end markets. This provided valuable validation of the UTS work.

3.3 Communication and media

The project has reached a large audience (+ 50,000 users) on social media (Twitter and LinkedIn) and has received coverage in more than 20 digital and print news publications. Highlights include articles in the following publications: The Age, Australian Manufacturing, Australian Printer Magazine, ProPack Magazine, Packaging News, Food and Drink Business, Inside UNSW and the University of Sydney website.

OP-ED

Navigating Australia's emerging circular economy

A circular economy for all industries is underway, and print has a huge part to play in its making too

The concept of a circular economy is gaining traction and print has a part in that evolution

Australian printers have a critical role to play in the emerging circular economy as the industry aims to redefine growth by focusing on the positive society-wide benefits of it.

NSW Smart Sensing Network (NSSN) Development Manager Dr Donald McCallum said like many other industries, print is going through significant technological change.

"By developing technologies that can improve substrates and adhesives, printers will have a greater say in what happens to their products post-consumption," Dr McCallum said.

"Australian universities and research institutions have a lot to offer with regards to developing innovative solutions for sensing contaminants and creating materials that will easily lend themselves to separation and ultimately recycling."

In a project coordinated by the NSSN, PEGRAS Asia Pacific and other major Australian companies will work with university researchers to develop solutions for sensing and treating residual contaminants on HDPE milk bottles.

The project aims to increase the percentage of recycled HDPE in materials recovery facilities (MRFs) by developing state of the art sensing technologies.

As part of this project, researchers from UNSW, University of Sydney and University of Technology Sydney (UTS) will develop methods to sense and remove the contaminants on HDPE plastic chips, scale the solution for deployment in recycling facilities and provide a high-resolution material flow analysis for the HDPE milk bottle supply chain.

Dr McCallum said with the Waste Export Ban coming into effect, it is crucial for Australian manufacturers to develop sustainable practices and use materials that are part of the circular economy.

> THE NSSN CAN BRING TOGETHER PRINT COMPANIES WITH SCIENTISTS AND ENGINEERS...

The Waste Export Ban prohibits the export of waste plastic, paper, glass and tyres that have not been processed into a "value-added" material.

"We are looking to expand the project from HDPE to other key polymers and objects like paper, glass and even RFID tags. We are happy to collaborate with printers working with complex materials," Dr McCallum added.

"The NSSN can bring together print companies with scientists and engineers and provide guidance on grants available."

A consortium of eight leading research universities from across NSW and the ACT, the NSSN brings together expertise in academia, industry and government to deliver innovative solutions to complex challenges. The NSSN has access to a pool of scientific expertise with application across a range of industries including the built environment, agriculture, medical technology, space, energy, data analytics and advanced manufacturing. It collaborates with industry and government to gain an in-depth understanding of their challenges and draws upon the strengths of leading research institutions to develop smart sensing solutions.

Managing consultant at PEGRAS Asia Pacific Dr Stephanus Peters said for the last 500 years print manufacturers have developed products with an eye to quality and quantity.

"It is only recently that we have realised these products have to be deconstructed in order to be recycled," Dr Peters said.

"Manufacturing a printed product with recycling in mind greatly increases the product's ability to be deconstructed at the end of life cycle, enabling it to contribute to the circular economy."

Dr Peters said by collaborating on research and development projects, local businesses and scientists can find solutions to problems such as de-laminating and de-inking, and as a result, improve the recyclability of printed products.

"There is an enormous potential for [research and development] projects with NSW universities," Dr Peters said.

"A Chinese Proverb says 'The best time to plant a tree was twenty years ago. The second-best time is now'. So, we may not be conditioned to solve problems by asking the universities, but if we don't ask, we will never know which solution they can bring."

*NSSN development manager **Dr Donald McCallum** and PEGRAS managing consultant **Dr Stephanus Peters** as interviewed by NSSN media and public relations officer Shahrzad Abbasi*

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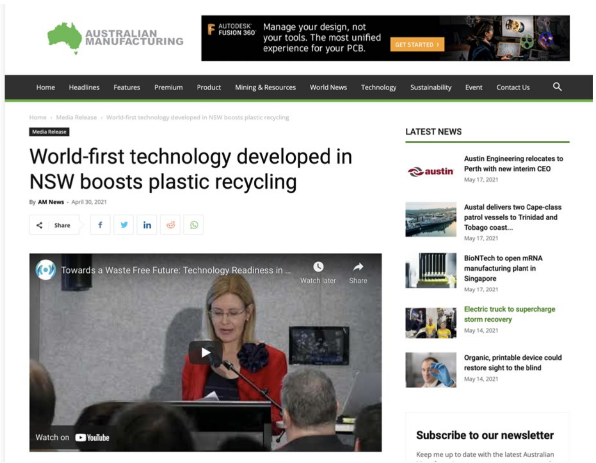
Smart sensing delivers HDPE recycling breakthrough

By Lindy Hughson | 29 April 2021



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Media Release

World-first technology developed in NSW boosts plastic recycling

By AM News · April 30, 2021

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Figure 3.3: Project publication highlights.

3.4 Project Management

The project reports overall highly effective and professional project management. The project was affected by COVID-19, dealing with delays, facility closures, personnel restrictions and additional stress and workload on staff. Despite this once in a lifetime challenge, project outcomes were delivered as planned.

3.4.1 Governance

The whole project team met online on a fortnightly basis for updates and collaboration. The meeting was coordinated by NSSN and chaired by PEGRAS. Minutes are kept on record. Additional meetings were organised as required.

3.4.2 Financial management

PEGRAS undertook day to day financial management. A formal audit of the project was undertaken in November 2021. Main income and expenditure items are shown in Table 3.1 and

Table 3.2.

Table 3.1: Budget income items

Contributor	cash amount (GST excl)	Estimated in-kind amount (GST excl)	Total (GST excl)
Grant	$650,000		$650,000
Dairy Industry	$37,500		$37,500
PEGRAS Asia Pacific Pty Ltd	$10,859	$103,198	$114,057
NSW Smart Sensing Network	$100,000	$64,077	$164,077
Labelmakers Group	$12,500	$230,135	$242,635
University of New South Wales		$100,050	$100,050
University of Sydney		$50,313	$50,313
University of Technology Sydney		$51,200	$51,200
Recycling sector	$50,000	$204,180	$254,180
Total	**$860,859**	**$803,153**	**$1,664,012**

Table 3.2: Budget expenditure items.

Head of expenditure	Breakdown of expenditure	Agreed project cost	Actual project costs
Eligible in-kind contributions	Non-cash in-kind contributions	$650,000	$803,153
Eligible expenditure	IP & Technology expenditure	$15,000	$14,971
Eligible expenditure	Capital expenditure	$52,111	$13,411
Eligible expenditure	Other eligible expenditure	$20,965	$2,437
Eligible expenditure	Audit costs	$14,000	$5,000
Eligible expenditure	Travel and overseas	$35,111	$13,488
Eligible expenditure	Contracts	$41,111	$46,811
Eligible expenditure	Labour including on-costs	$671,702	$764,741
All financial years total		**$1,500,000**	**$1,664,012**

4 Results

4.1 Sensing and polymer science

The objectives of the KCPC with regards to addressing the label and polymer chemistry removal problems have been thoroughly met and exceeded. The actual sensing, as realised through the materials characterisation is demonstrated in several ways. The KCPC group successfully imaged the flakes showing bonding between the polymer substrate and label (see Figure 1.2). Industry has at its disposal a newly developed analytical technology including the use of FT-IR (see Figure 4.1), which can efficiently quantify glue contents in plastic with high degree of accuracy. It was found that substantial amount of glue (approximately 50% or more) remained in recycled HDPE after washing compared to before washing.

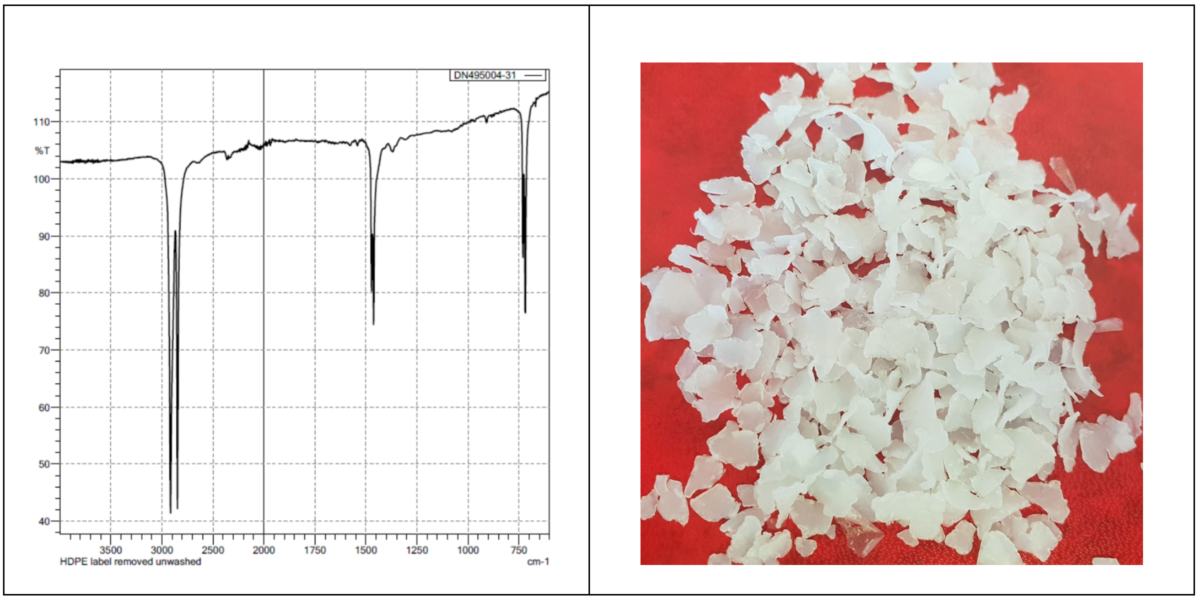

Figure 4.1: (left) The FT-IR spectrum of a HDPE flake showing no glue attached after undergoing KCPC impact delamination process. (right) Clean HDPE flakes from a 2 litre milk bottle after impact delamination and washing process using the new technology developed by A/P Brian Hawkett and Dr Duc Nguyen at KCPC, The University of Sydney.

Impact delamination technology delivered comparable clean HDPE flakes without any chemical washing, as shown in Figure 4.1. The KCPC analysed HDPE test flakes with new glue and label composition from Labelmakers and made recommendations for improvements.

It was found that glue recontamination in recycler's wash process could be reduced with process optimisation. It was confirmed that the prototyped reactor designed by UNSW delivered washed HDPE flakes as clean as from the recycling facility process.

4.2 Modelling, prototyping and scale-up

The ProMO laboratory has made significant progress in the model development of the current industry HDPE washer reactor. An advanced mathematical model has been developed for describing the complex multiphase flow during the adhesive removal process to understand the details of internal phenomena inside the reactors, where a high-quality mesh and models are set up, as shown in Figure 4.2.

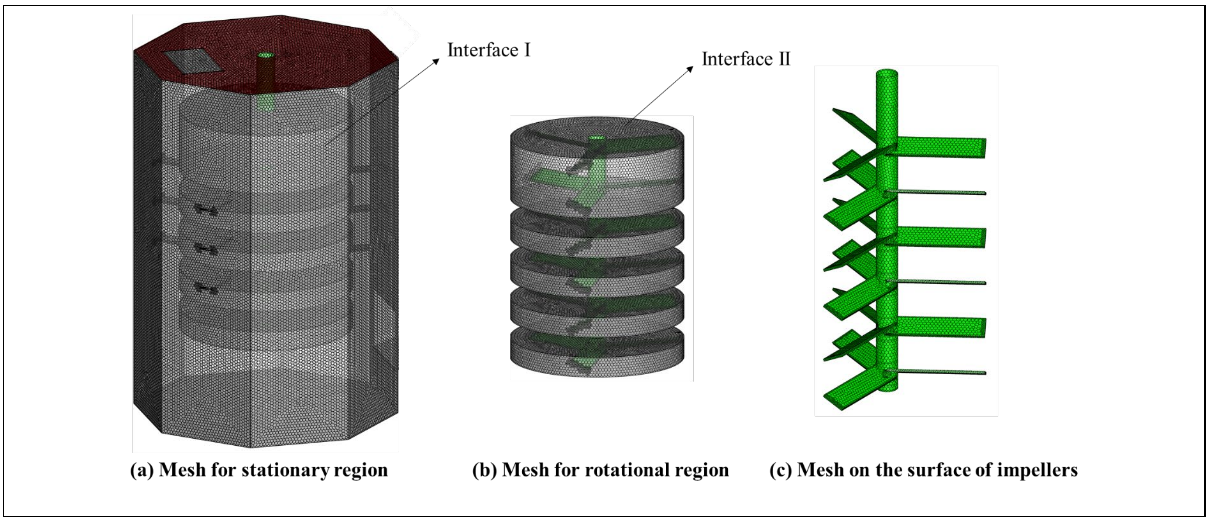

Figure 4.2: The modelling mesh showing stationary region, rotational regions and impellers.

Many key internal phenomena which are difficult to be observed in the actual washing process, were revealed by simulation work, as shown in Figure 4.3. The influence of several critical operating conditions on adhesive removal performance is investigated and compared in detail. The optimal operating settings were then identified.

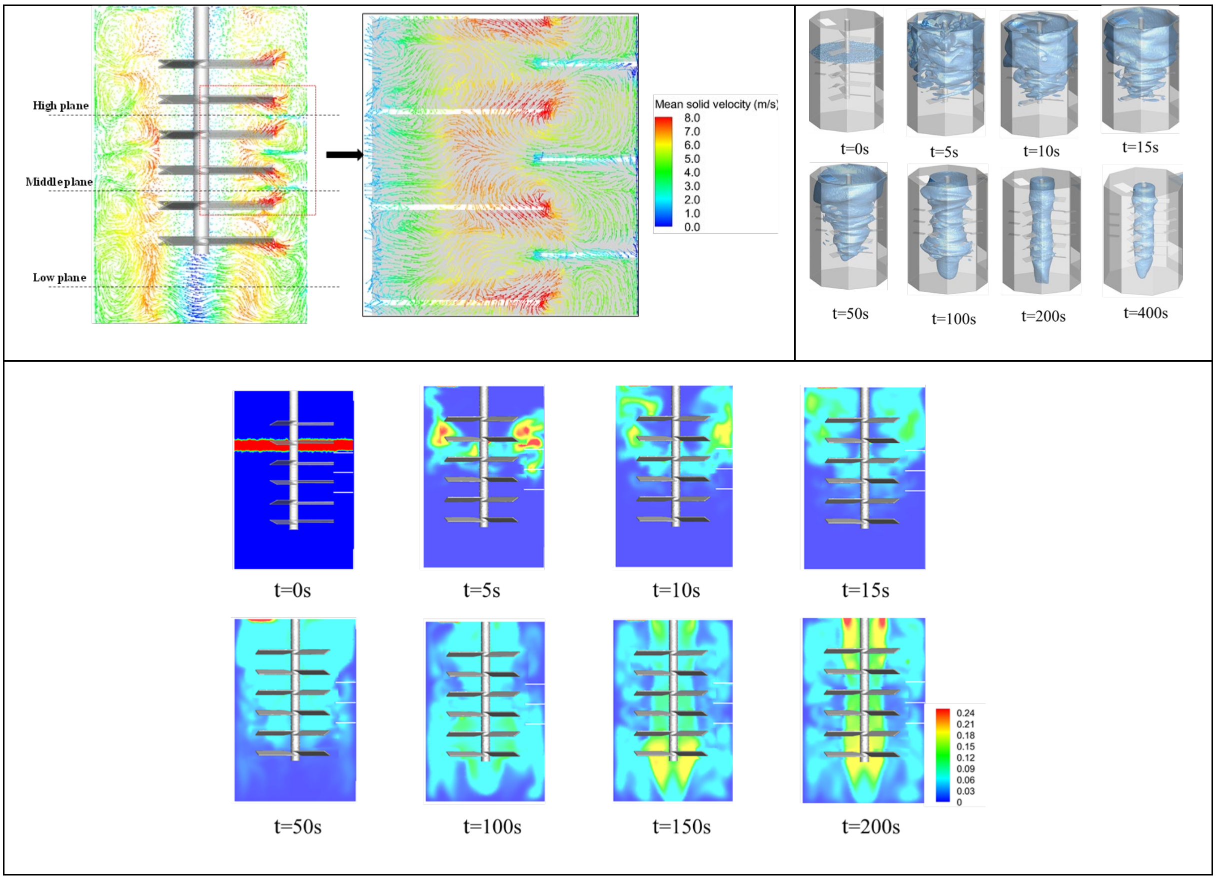

Figure 4.3: Simulations showing variations to feed ration, temperature, and rotational speed (Clockwise from top left).

Simulation results show that decreasing rotation speed and solid feeding ratio, and increasing the operating temperature is conducive to increasing the removal efficiency (see Figure 4.4). Some suggestions for improving removal efficiency are put forward. A laboratory test rig is designed and set up for concept proof and model validation, as shown in Figure 3.1.

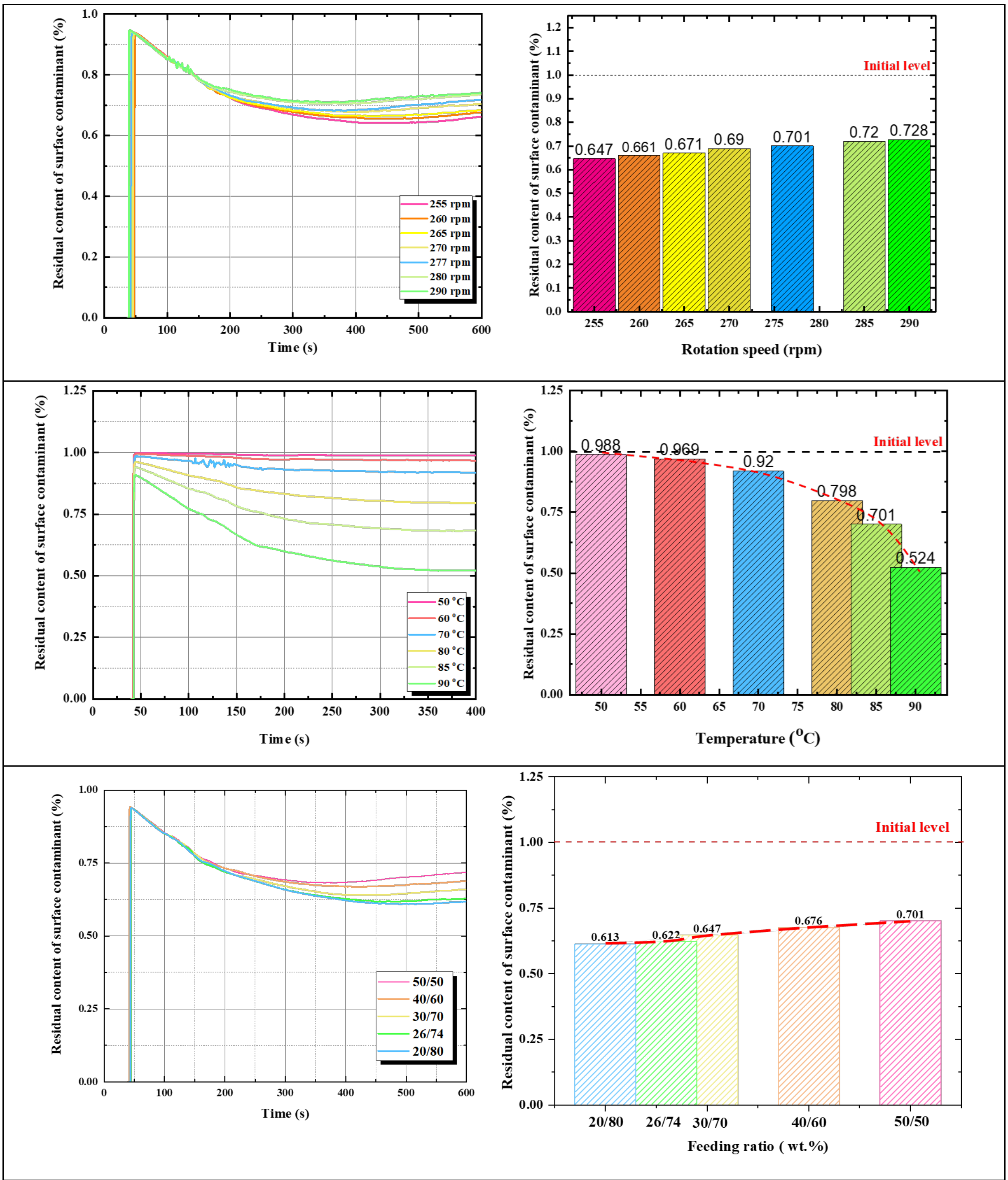

Figure 4.4: Simulations to arrive at the optimised operational settings for rotation speed, temperature and feeding ration.

4.3 Material flows

To map the baseline material flows of HDPE milk bottle packaging in Australia the ISF used Dairy Australia data of local milk consumption, Labelmakers data on types/size of bottles placed on the market, APCO reprocessing data and life cycle analysis data on material recovery facility performance. They identified the distribution of the HDPE packaging for milk by packaging size, material type for the bottle, label, adhesive and cap.

Findings reflected that Australians consume 1 billion milk products each year, predominantly sold in 2L milk bottles (65%) and 3L milk bottles (25%). Post-consumer HDPE milk bottles (48 kilo tonnes) are collected predominantly at the kerbside (88%) – municipal solid waste (MSW) and 11% through commercial and industrial collection. In the states that currently have a container deposit scheme in place only small containers (<1L) are considered and 1% of the postconsumer milk bottle HDPE is collected. However, most of the postconsumer HDPE (59%) is not collected for recycling and is disposed to landfill predominantly due to poor disposal practices (e.g. disposal in the red bin) and a small proportion is owing to a lack of convenient recycling services. A significant proportion of sorted milk bottle HDPE (40%) is baled for export (coming to an end in 2022 with the implementation of the waste export ban) with less than half (4 kilo tonnes) of locally reprocessed HDPE is natural. 59% of the locally reprocessed HDPE is reprocessed into packaging and the rest is downcycled for industrial applications. Our analysis identified low recovery rates (38%), very small local utilisation rate (17%) and even smaller circularity rate (10%) for milk bottle HDPE, all falling short of the targets of 70% recycling rate and 20% recycled content by 2025.

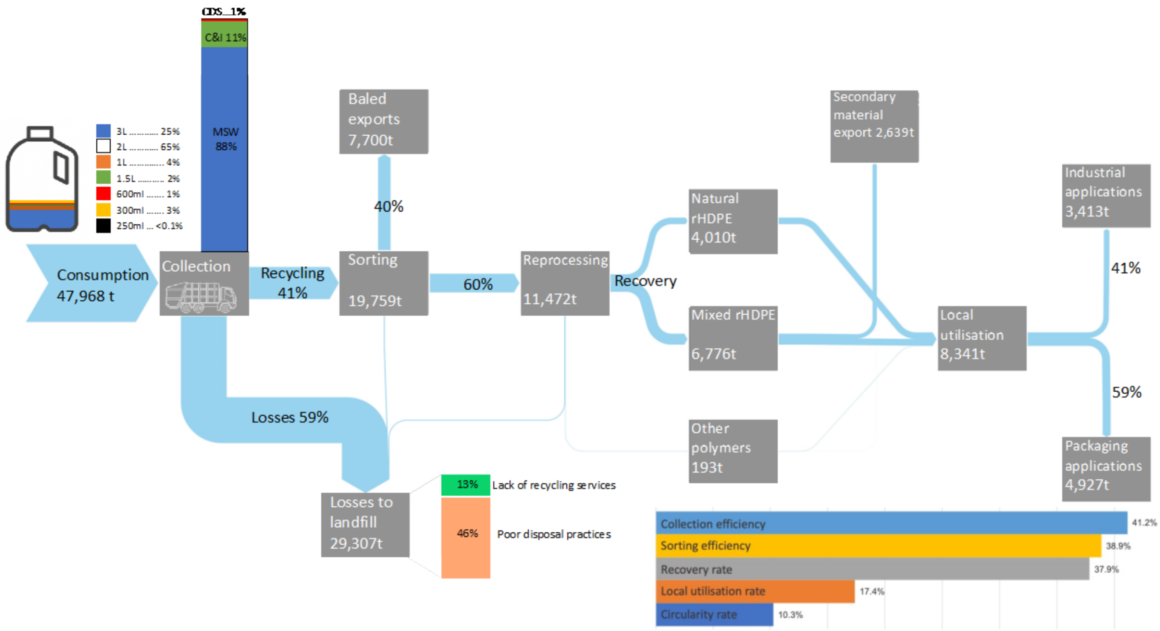

Figure 4.5: Material flow diagram for HDPE milk bottle, including the distribution of milk bottles by size, collection by collection stream (CDS, C&I, MSW), breakdown of losses to landfill and the system efficiency rates (collection, sorting, recovery, local utilisation and circularity).

ISF modelled possible future scenarios based on consumption trends and proposed reprocessing capacity expansion, policy signals (including waste export bans and CDS expansion) and consultation with the industry experts. In the scenario modelling we explored measures to increase collection rates, such as expansion of the CDS scheme across all jurisdictions in Australia, as well as inclusion of containers >1L. However, even in the heroic scenario, 70% recycling rate could not be reached. We also explored the pathways to circular economy for HDPE milk bottles (recycling bottle to bottle), one of the important steps in establishing high value end markets. While clear guidance from Food Standards Australia New Zealand (FSANZ) and other incentives such as taxation measures observed in UK might be required to increase the recycled content, the modelling suggests that with improving label and adhesive design, recovery technology and reprocessing capacity, 20% recycled content target can be achieved.

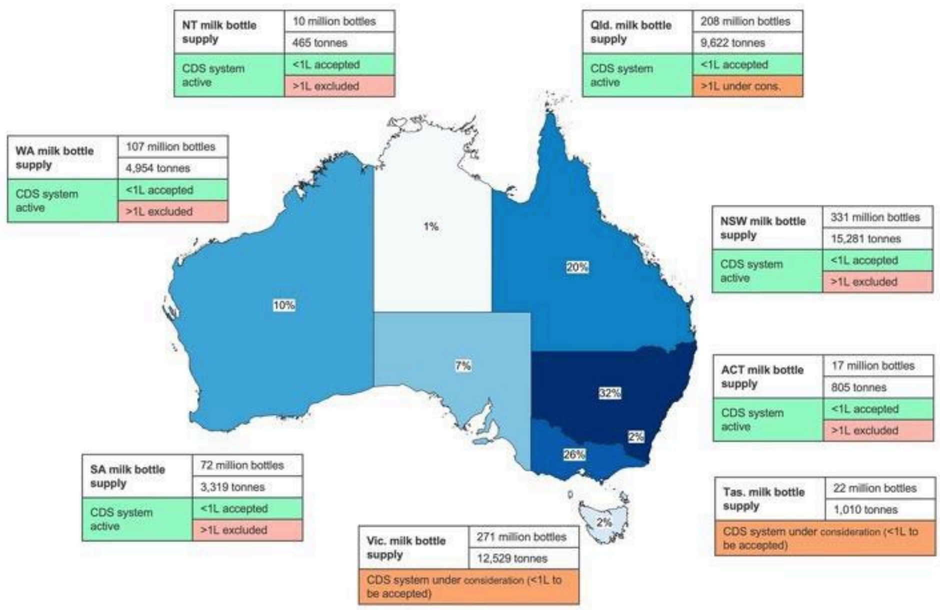

Figure 4.6: Milk supply distribution by state and CDS system review by state

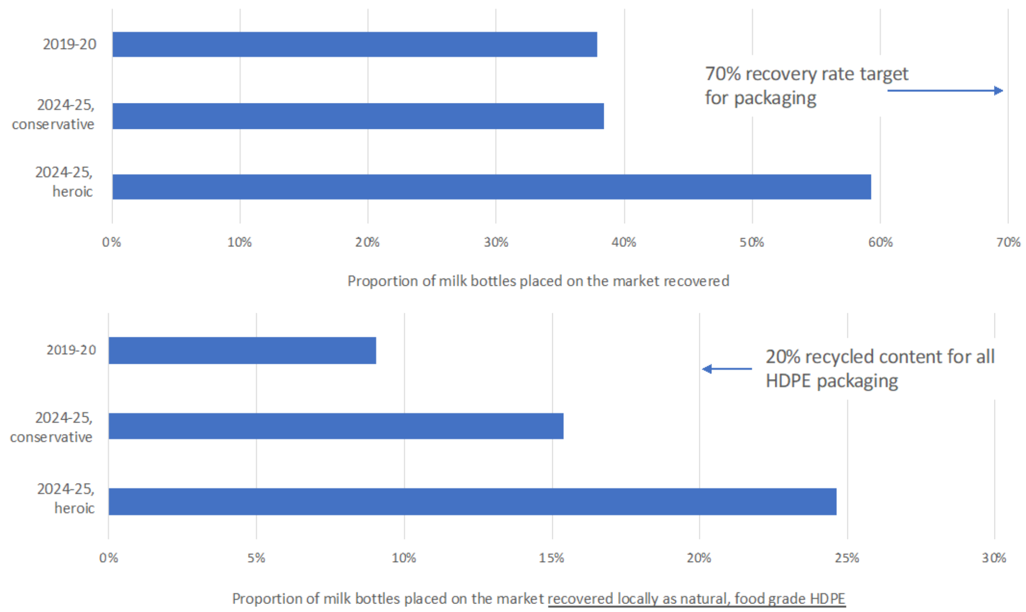

Figure 4.7: Comparison of the local recovery volumes under the conservative and heroic scenarios with the recycling rate target and recycling content target.

5 Project impact

5.1 Overall outcomes

This project solved a global problem of how to effectively remove the glue that holds the milk label to the plastic bottle, that has been contaminating the industrial washing process of recycling food grade HDPE for the past 20 years. This will help enable the recycled content of HDPE to be increased to 50% and support the transition to the circular economy for the 48,000 tons pa of HDPE plastic used for fresh milk production in Australia.

A world first test method was developed for sensing glue residue on recycled HDPE that led to the development of improved adhesive chemistry, more responsive to the washing process. Super-computer-based modelling was used to virtually simulate the full-size industrial recycling wash reactor. This facilitated the scaled down design and construction of a laboratory size, mini recycling wash reactor 'test-rig' at 2% of production volume. This will accelerate future label and plastic packaging designs to be optimised for circularity. Designs can be validated in the test-rig prior to launching onto the market at full scale.

This project ultimately engaged the full spectrum of companies in a cross-industry collaboration involving the total supply-chain of fresh milk supply in Australia, from dairy manufacture and packaging to supermarket and consumer consumption, to recycling.

The project has had a direct impact on the development of policy and strategy to meet the 2025 National Packaging Targets and the transition to a circular economy. Specifically, the material flow analysis of the HDPE milk bottle system, from consumption to recovery at EOL, has informed the APCO and Dairy Australia Sustainability Working Group Dairy Packaging Roadmap to 2025.

With specific reference to the technology innovation developed in this project, the team has demonstrated a recovery pathway for valuable food-grade HDPE that uses established mechanical recycling systems coupled with the advanced label and adhesive removal technology.

5.2 Technical outcomes

The project has identified that milk bottle recovery rate is below the 70% recycling rate target. Considering that natural HDPE recycling is considered to be well established, particularly when compared to troublesome soft plastics, this highlights the significant challenge in achieving the target . ISF identified that high collection losses are the greatest barrier to improve the recovery rate (59% lost to landfill) and could be addressed by diversion of used milk bottles out of MSW and C&I (commercial and industrial waste collection) to a more efficient CDS and with increasing CDS product eligibility and redemption rates. Expansion of kerbside recycling services to all jurisdictions and better at home consumer awareness and disposal practices is also required.

Local recovery volumes of natural HDPE are sufficient to achieve the recycled content target of 20% for HDPE packaging, however sufficient local demand must exist. This includes removing the contaminants in recovered HDPE for food-grade applications. Using existing mechanical recycling systems, with advanced label and glue removal technology developed in this project, provides an opportunity to shift recoveries from industrial-grade (non-food-grade) recyclate to food-grade by addressing contamination.

Our findings and results have informed the development of the APCO and Dairy Australia roadmap for dairy packaging and have been summarised in a public summary report. An opinion piece has also been submitted to the Australian Packaging Magazine. Two peer reviewed academic publications are in preparation and a Conversation article.

When looking inside the machinery and process the project can state the following engineering and scientific outcomes.

- An advanced mathematical model was developed for describing the complex multiphase flow during the adhesive removal process so as to understand the details of the internal phenomena inside washing reactors.
- The developed model was applied to the current NaOH based removal process used at the recycler and the complex multiphase flow during the adhesive removal process inside the reactors was better understood.
- Mathematical models run on a supercomputer were used to test and evaluate different operational scenarios extensively and some suggestions for improving removal efficiency were put forward.
- A laboratory test rig was set up for concept proof and model validation.
- The actual sensing or materials characterisation was demonstrated in several ways such as FT-IR, micrograph imaging and other chemical analysis.
- Materials characterisation chemistry process allows for immediate uptake by private industry to implement better quality controls and recycling improvements. It is considered a unique and inventive step, and the patenting process has commenced.

5.3 Stakeholder quotes

The project has attracted the attention of a range of key industry, research and government observers from within and outside of the project. This series of quotes provide a neat, holistic summary of how the project outcomes are viewed.

Dr. Stephanus Peters (Managing Consultant - PEGRAS)

> *"PEGRAS believes in the circular economy. The CRC-P grant has helped us to develop solutions to clean labels and adhesive off HDPE milk bottles which increases its recyclability."*

Ian Olmstead (Program manager – Manufacturing Innovation and Sustainability for Dairy Australia)

> *"It's really pleasing to see this cross-industry collaboration by major dairy players like Saputo Dairy Australia, Lactalis Australia and Bega Cheese to support the industry's continued progress towards improving the recyclability of dairy product packaging and*

meeting the National Packaging Targets. We are fortunate to be able to draw upon world-class research organisations like UTS and PEGRAS as well as the support of other packaging suppliers such as Labelmakers to develop novel technologies for advanced recycling and increase local capability. The project has been a great template for how industry can work together and is well timed, given the imminent launch of the Australian Dairy Sustainable Packaging Roadmap by APCO, Dairy Australia and the Australian Dairy Products Federation."

Graeme Lang (Group Technical Manager – Labelmakers Group)

"From an industry partner perspective, a major impact of the CRC project - to increase recycling of HDPE packaging by sensing and treating label contamination - has been the development of solutions to a problem that industry alone has been unable to solve.

Without means of facilitating genuine circularity – returning significant quantities of resin recovered from spent HDPE dairy bottles back into new food grade HDPE dairy bottles – HDPE as a form of packaging for food products is becoming exposed to increasingly higher financial and environmental costs at the hands of increased disposal / land fill charges and greater resource depletion.

Whilst alternative forms of packaging fresh dairy products such as glass have established recycling pathways they involve inherently much higher environmental costs associated with the manufacture of new and recycled containers.

The headline outcomes from this research project include:

i. The development of an accurate real time measurement of adhesive impurities in the recovered HDPE flake

ii. The application of computer modelling to optimise recycling plant design and operating efficiency

iii. The development of impact delamination to remove some of the adhesive prior to washing and

iv. Improved label and adhesive design

can give rise to significant lessening of adhesive contamination in the recovered rHDPE flake accompanied by a reduction in the time, energy and resources to achieve the desired outcome

However perhaps a less obvious but wider reaching and more enduring impact of the CRC Research project has been the creation of a platform for Labelmakers and the industry more generally to impartially and factually assess future developments in recycling-enabling packaging design through the creation of the pilot test rig."

Dr. Nick Florin (Research Director - Institute for Sustainable Futures, University of Technology Sydney)

"This project has had a direct impact on the development of policy and strategy to meet the 2025 National Packaging Targets and the transition to a circular economy.

Specifically, the material flow analysis of the HDPE milk bottle system, from consumption to recovery at EOL, has informed the APCO and Dairy Australia Sustainability Working Group Dairy Packaging Roadmap to 2025.

With specific reference to the technology innovation developed in this project, the team has demonstrated a recovery pathway for valuable food-grade HDPE that uses established mechanical recycling systems coupled with the advanced label and adhesive removal technology. While incentives to increase demand for recycled content may be needed to accelerate technology deployment sector-wide, this represents an important step towards a true circular economy for HDPE packaging."

Dr. Donald McCallum (Theme Leader: Industrial Futures – The NSW Sensing Network),

"The NSSN as a network of universities, whose main goal is to assist industry with the translation of research into industry practice, has benefited from this project as a showcase example of university, small and big business collaboration."

Professor Yansong Shen (School of Chemical Engineering, University of NSW)

"The advanced mathematical model developed in this project can reveal the complex multiphase flow during the adhesive removal process inside the washer, which is very important in the process illustration and reactor scale-up.

The mathematical model can be used to evaluate and test new designs and different operational scenarios extensively. Some optimisation strategies have been proposed to improve the washing efficiency and a significant improvement has been made.

The scalable mathematical model offers a powerful and cost-effective tool for process design and optimisation, and more importantly for industrial upscaling, from laboratory-scale concept proof to industry-scale technology demonstration and implementation."

Damon Norton (Packaging Specialist Sustainability & Health, Woolworths Limited)

"Increased recovery rates and subsequent pull through of recycled material are pivotal to a circular plastic economy for packaging. Academic, government and industry partnerships such as this are to be applauded for their collaboration; this CRC-P solves an important challenge in a way that can be scaled and implemented for meaningful impact to recovery rates."

Associate Professor Brian Hawkett (Director - Key Centre for Polymers and Colloids, University of Sydney)

"The Key Centre for Polymers and Colloids has been collaborating with industry for more than 22 years. Academically we have generally collaborated with academics from the School of Chemistry, or other schools within The University of Sydney. We have not previously collaborated, on the same project, with such a broad range of industry

partners nor academics from as broad a range of universities. This project has provided an exciting learning exercise as we have adapted to this new way of operating."

Professor Edward Kosier (Managing Director Nextek | NEXTLOOPP)

"There have been major innovations in the recycling of plastics packaging in terms of precision of sorting, cleaning, separation and decontamination that allow the production of polymers that can be readily re-used in applications in place of virgin resins. The application of science underpinning these stages needs to be well understood to provide reliable and risk-free circular resins. This report makes an important contribution in this area."

5.4 Publications

5.4.1 Conference presentations

1. Shuyue Li, Yuting Zhuo and Yansong Shen, Process modelling and optimisation of label removal process for HDPE recycling. Towards a Waste Free Future: Technology Readiness in Waste and Resource Recovery, 27 April 2021 (Oral presentation).

2. Shuyue Li, Yuting Zhuo and Yansong Shen, CFD investigation of high-density polyethylene (HDPE) flakes recycling in the washing process, The 8th Asian Particle Technology Symposium, 11 October - 14 October, 2021 (Oral presentation)

3. Shuyue Li, Yuting Zhuo and Yansong Shen, Design of the laboratory scale stirred tank test rig for HDPE washing process. Towards a Waste Free Future: Technology Readiness in Waste and Resource Recovery, 27 April 2021.

4. B. Liang, J. Xu, Z. Li, S. Liang, Y. Wang, F. Chen, D. Vitanage, R. Nikoloska, "Critical and Small Pipe Prediction within 200m of failure", Ozwater21, 2021.

5.4.2 Publications in scientific journals

1. Shuyue Li, Yuting Zhuo and Yansong Shen, CFD investigation of high-density polyethylene (HDPE) flakes recycling in the washing process, Applied energy. (To be submitted)

2. Shuyue Li, Yuting Zhuo and Yansong Shen, CFD investigation of the effect of operating conditions on the high-density polyethylene (HDPE) flakes recycling in the washing process, Resources, Conservation& Recycling . (To be submitted)

3. Shuyue Li, Yuting Zhuo and Yansong Shen, Experimental study on the washing process of high-density polyethylene (HDPE) flakes in a lab-scale stirred tank. Resources, Conservation & Recycling. (To be submitted)

5.5 Reports and communication

1. Byrne, I. Increased recycling of plastics by sensing and treating label contamination. Final Report submitted to the CRC-P, October 2021.

2. Florin, N., Jazbec, M., Madden, B., Pathways towards circularity in HDPE packaging: material flow analysis and best practice guidance. March 2021. NSSN Fact Sheet prepared by UTS.

3. Hawkett, B., Nguyen, D., Huynh, V., Priyananda P. Label contaminant sensing and impact delamination breakthrough. March 2021. NSSN Fact Sheet prepared by The University of Sydney.

4. Jazbec, M., Madden, B., Florin, N. (2021) Pathways towards circularity for HDPE packaging. A CRC-P summary report prepared by Institute for Sustainable Futures.

5. Li, S.,Zhuo, Y., and Shen, Y., Wash reactor computer simulation and process optimisation. March 2021. NSSN Fact Sheet prepared by UNSW.

6. McCallum, D., Saraswati., A. New technology for sorting and recycling from advance sensing to artificial intelligence. March 2021. NSSN Fact sheet.

7. Peters, S., Byrne, I. Increased recycling of plastics by sensing label contamination. March 2021. NSSN Fact Sheet prepared by PEGRAS.

8. Retamal M, Dominish E, Wakefield-Rann R, Florin N. Think all your plastic is being recycled? New research shows it can end up in the ocean, 3 Mar 2021, The Conversation.

9. Wakefield-Rann R, Florin N, Downes J. Recycling plastic bottles is good, but reusing them is better 5 Nov 2021, The Conversation.

5.6 Patents[1]

The IP brought to the project regarding impact delamination has given every indication it will effective for the needs of industry and has been supported by the project. This IP remains with The University of Sydney.

The relevant number is PCT/AU2021/050523 and is titled "A PROCESS FOR RECYCLING A LAMINATE AND A SOLUTION THEREFOR" by A/prof. Brian Hawkett, Dr Duc Nguyen, Dr Vien Huynh, Dr Pramith Priyananda as the inventors and with The University of Sydney as the applicant.

The discovery that the impact delamination process could facilitate the solvent free removal of labels and glue from HDPE milk bottles was made in March 2019. It is considered that this inventive step is non-severable from the existing IP application. This was coupled with the discovery that an appropriately designed caustic, surfactant and solvent blend, that stabilised a glue emulsion at low temperature and allowed it to phase separate at high temperature, could be coupled with impact delamination to remove the last vestiges of glue remaining on the recycled HDPE flake. These two aspects of glue and label removal were incorporated into provisional patent application number 2020901775, lodged on 29 May 2020. This patent is about to go into the international phase, with a view to its prosecution in the following jurisdictions: Australia, New Zealand, US, GB, EU and South Africa. This patent has broader application for use with polymers than just HDPE, and this broader application will be claimed.

[1] These are summary notes only and should not form the basis of any formal IP discussion.

6 Future work

Figure 6.1: Concepts from the project have the potential to be applied to other polymers, such as these PET bottles.

6.1 Circular economy

A key intervention to increase recycling rates and meet targets involves improving collection and this could be achieved by expanding CDS to include larger container sizes and across all states and territories. Clear guidelines on food-safety standards, as well as incentives to increase demand for recycled content as observed internationally, will likely be needed accelerate the system changes supporting recycling targets and circular transitions. ISF recommends exploring equitable ways to share the increased cost across the supply chain aiming to increase the recycled content through the mechanical recycling.

The findings from this study apply to other packaging material streams and widespread adoption of the range of interventions explored are needed to transition to a circular packaging economy.

6.2 Follow on experiments

The work can be further informed by testing a range of new designs and operational scenarios in the lab-scale test rig. These are shown in Table 6.1

The lab-scale test rig can be configured to explore new removal chemistry process.

Mathematical modelling supported by laboratory-scale experiments on the test rigs will target the re-manufacture of 100% recycled HDPE (rHDPE) content.

The scale up of impact delamination technology has a high likelihood of success and this should be facilitated at the next level up.

A second provisional patent is presently being drafted to cover a new test method that can be used to accurately measure the residual glue in a sample of recycled HDPE flake ("Test method IP" with inventors Associate Professor Brian Hawkett, Dr Duc Nguyen, Dr Minh Lam and Dr Vien Huynh). The final patent may well have application for use with a broader range of plastics this is expected to be claimed. Ownership of both patents presently rests with The University of Sydney but there is a stated intension that a formula will be negotiated to transfer control of the Test Method IP to the CRC-P Project lead, PEGRAS, under the terms of the CRC P Partners Agreement.

6.3 Exploitation of outcomes

The analytical technique developed by The University of Sydney is a useful tool which should be adopted as the standard method to measure glue contaminants in plastics, across Australia and possibly globally. The most important aspect is to set maximum acceptable glue levels which may be permitted especially for food grade. The KCPC also recommends more widespread use of analytical techniques in factories to better control recycled material quality.

The numerous simulation, modelling and process findings developed by UNSW can be readily adopted by a number of industry partners.

The ISF findings can continue to inform industry and government in understanding materials flows and setting policy.

6.4 Smart sensing and other initiatives

Members of the project team are about to embark on a project for recycling waste hospital polymers plastics, which have drastically increased due to covid.

From among the team, another proposal is underway for the recycling of solar panels; another for better disposal millions of tonnes of waste paper, there is keen interest for a localised recycling mini-factory to process bottles close to the source.

The ongoing progress of data analytics, in particular artificial intelligence (AI) and machine learning (ML) concepts are highly applicable to the sorting processes that underpin recycling.

Advanced sensing, sensing fusion, multimodal sensing and better utilisation of data uncertainty analysis can all assist the recycling industry.

Table 6.1: Proposals for a parameter variation experiment using the test rig. The left side settings are the settings to be varied based on the recycling facility, and the right side is the baseline.

Recycler					Baseline				
	Current	Options	Options	Options	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
Temp	85° C	70° C	60° C	50° C	85° C	85° C	85° C	60° C	
	85° C	70° C	60° C	50° C					
	85° C	70° C	60° C	50° C					
	85° C	70° C	60° C	50° C					
NaOH %	1.50%	2.00%	2.50%	3.00%	1.50%	1.50%	2.50%	2.50%	
	1.50%	2.00%	2.50%	3.00%					
	1.50%	2.00%	2.50%	3.00%					
	1.50%	2.00%	2.50%	3.00%					
surfactant	0.05%	0.10%	0.15%	0.20%	0.05%	0.05%	0.05%	0.05%	0.15%
	0.05%	0.10%	0.15%	0.20%					
	0.05%	0.10%	0.15%	0.20%					
	0.05%	0.10%	0.15%	0.20%					
Label material									
Face Stock	BOPP	PET	HDPE		BOPP	BOPP	BOPP	BOPP	BOPP
Glue	SP	WH			SP	WH	WH	WH	WH
Other									
blade RPM	277				280	280	280	280	280
flake/wash	TBC				26/74	26/74	26/74	26/74	26/74
flake kg (from					7	7	7	7	7
Wash L					20	20	20	20	20
Dwell time	15				20	20	20	20	20
Notes	7 kg flake to 20 L wash								
	samples to be tested by Sydney								
	flakes to be supplied by LM of known glue % (0.45%)								
	500 gram washed sample to be collected for Sydney								
	Baseline to match full size Telford trials