Final Report

AMPC
AUSTRALIAN MEAT PROCESSOR CORPORATION

Accelerating biogas productivity and adoption with AnCoD pilots

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1.0 Abstract

This project was undertaken to support the red meat processing industry in adopting new ways to turn organic waste into renewable energy. It focused on using a process called anaerobic co-digestion, where different types of organic waste are treated together to produce methane-rich biogas, which can be used to power operations and reduce greenhouse gas emissions.

To help processors trial this process safely and effectively, the project designed, built, and delivered two automated pilot-scale digesters, each holding 400 litres. These units were manufactured in Germany and carefully tested before shipping to Australia. After facing several challenges in finding a suitable host site, the project team established a purpose-built research and development facility—the Tessele Bio Hub—in Perth, Western Australia. This facility meets all safety and technical requirements and allows controlled testing and demonstration of the technology.

The key results include successful international delivery, full testing and safety approval, and installation of the pilot units in a new dedicated facility. The project also engaged stakeholders through a showcase event, generating strong interest in future trials.

The outcome of this project provides the industry with a practical, ready-to-use platform for testing renewable energy solutions on-site. It reduces technical risk, supports knowledge-sharing, and brings the red meat sector closer to adopting waste-to-energy technologies that improve sustainability and lower costs.

2.0 Executive summary

This project was developed to help the red meat processing industry explore cleaner, more cost-effective ways to manage waste and energy. Many processors are interested in converting organic waste into renewable energy, but face challenges in trialling new systems safely and efficiently. Anaerobic co-digestion (AnCoD)—a process that combines red meat waste with other organic materials to produce biogas—offers a promising solution. This project focused on removing barriers to adoption by creating a fit-for-purpose pilot-scale testing platform.

The main target audience includes red meat processors, plant managers, and industry partners seeking to reduce energy costs, cut emissions, and make better use of organic waste streams. With a proven platform for small-scale testing now in place, the industry can move more confidently toward adopting waste-to-energy technologies.

The project aimed to design, build, and install two 400-litre automated anaerobic digesters suitable for pilot trials. These units were successfully manufactured in Germany, fully tested during a Factory Acceptance Test, and delivered to a newly established research facility—Tessele Bio Hub—in Perth, Western Australia. All objectives were achieved, including creating a safe and compliant environment for trials, overcoming earlier barriers to institutional hosting, and generating stakeholder interest.

To meet the project's goals, a practical and flexible approach was taken. Custom-built equipment was paired with rigorous safety and compliance assessments. When initial host site options proved unfeasible, the project team adapted by setting up an independent R&D facility that meets technical, zoning, and operational requirements.

The result is a high-quality, ready-to-use pilot platform. Both digesters are now installed and operational, enabling the red meat industry to begin testing co-digestion scenarios using real waste streams. The stakeholder showcase held in March 2025 generated strong industry interest, confirming that there is an appetite for further trials and broader adoption.

The key benefit to industry is a safe, low-risk opportunity to trial AnCoD at a scale relevant to commercial operations. This infrastructure supports future research into energy recovery, operating cost reduction, and emissions management—advancing the industry's circular economy goals.

Looking ahead, the next steps include wet commissioning, live-feed trials, and data collection on biogas yields and performance. The project recommends expanding industry involvement through pilot participation, knowledge-sharing activities, and follow-up research that tests a broader range of waste combinations and operating conditions. This will provide practical guidance to processors considering AnCoD for long-term use.

3.0 Introduction

The Australian red meat processing industry generates a significant volume of organic waste and consumes large amounts of energy in its day-to-day operations. Despite the potential to recover value from these waste streams, adoption of energy-from-waste technologies—particularly anaerobic digestion—remains limited. Barriers include infrastructure costs, operational complexity, site-specific risk factors, and the absence of a fit-for-purpose testing platform that allows processors to trial anaerobic digestion at manageable scale.

This project was initiated to close that gap. It addresses a clear industry need: to develop and demonstrate a safe, scalable, and practical system for trialling anaerobic co-digestion (AnCoD)—a process that combines red meat waste with compatible agricultural residues to generate methane-rich biogas. The aim was not to develop new technology, but to provide the missing middle step between lab-scale research and full-scale commercial implementation. By building, delivering, and installing two pilot-scale digesters designed specifically for industry engagement, this project enables processors to validate AnCoD on-site before investing in larger systems.

Previous research has confirmed the technical viability of anaerobic digestion for the red meat industry (Tucker et al., 2010; FSA Consulting, 2014; AMPC 2022). However, the leap from technical reports to operational deployment remains large, especially for facilities in regional or infrastructure-constrained locations. This project is unique in that it doesn't propose a one-size-fits-all design, but rather offers a mobile, modular testing platform that supports learning-by-doing. The 400L digesters allow users to test real feedstock combinations, monitor biogas yields, and evaluate operational fit in a controlled, low-risk environment.

The central question this research sought to answer was: **Can we reduce the risk and increase the confidence of red meat processors in adopting co-digestion technologies by providing access to well-instrumented, pilot-scale digesters?** This question is rooted in the recognition that site-specific variation in waste quality, operational schedules, and regulatory conditions demands a flexible, trial-ready solution. Processors have expressed uncertainty around feedstock behaviour, biogas quality, maintenance needs, and system reliability. This project directly responds to those concerns.

The target audience includes plant operators, engineering managers, environmental and sustainability officers, and broader stakeholders such as government regulators and research collaborators. These groups need access to practical demonstrations and performance data to support decision-making. Importantly, the pilot units also serve as a learning tool for workforce training, capacity building, and stakeholder engagement—addressing both technical and cultural adoption barriers.

The outcomes of this research will be used to guide the next stage of pilot trials under the RACE for 2030 framework and inform broader adoption strategies for energy recovery in the red meat sector. By validating equipment readiness and establishing a dedicated facility—the Tessele Bio Hub—this project lays the foundation for testing

waste-to-energy scenarios, benchmarking emissions reductions, and modelling return on investment. It also enables collaboration across facilities, researchers, and technology suppliers, accelerating knowledge transfer and adoption.

4.0 Project objectives

The objective of this project was to enable pilot-scale anaerobic co-digestion (AnCoD) trials to support the red meat industry in adopting high-performance, methane-rich biogas systems. This was to be achieved by procuring, delivering, installing, and preparing for the commissioning of two 400-litre, fully automated anaerobic digestion reactors. These pilot units provide a controlled, practical platform to test waste-to-energy opportunities at site level.

The specific project objectives, as outlined in the research agreement and delivered under this stage of the project, were:

- Complete the Factory Acceptance Test (FAT) for both reactors at the manufacturing facility in Dresden, Germany, to validate technical functionality, automation features, and safety compliance prior to shipping.
- Manage international freight logistics, including insurance and customs clearance, to ensure secure delivery of the reactors from Germany to Australia.
- Conduct detailed risk and safety assessments, including a Hazardous Area Classification (HAC) in accordance with Australian standards (AS/NZS IEC 60079.10.1:2022), to support compliant installation.
- Resolve host site constraints by establishing a dedicated research and development facility—the Tessele Bio Hub—in Myaree, Western Australia, which meets all technical, zoning, and operational requirements.
- Deliver and install both 400L pilot reactors at the new facility, including all electrical, ventilation, and safety system integration to ensure installation readiness.

These objectives were successfully completed, providing the industry with its first independent, fully compliant pilot-scale platform for advancing anaerobic co-digestion in the red meat sector..

5.0 Methodology

The project was conducted through a series of carefully sequenced and interdependent phases, each designed to ensure the successful procurement, delivery, compliance verification, and commissioning readiness of two 400-litre anaerobic co-digestion (AnCoD) pilot reactors. Although this phase of work did not include live-feed biological trials or statistical analysis, it established a technically robust and safe foundation for the upcoming operational phase by applying rigorous engineering validation, safety assessments, and logistical planning.

The process began with the international procurement of two fully automated anaerobic digesters from Umwelt- und Ingenieurtechnik GmbH Dresden (UIT GmbH), a specialist German manufacturer. Each unit was pre-designed for continuous stirred-tank reactor (CSTR) operation, with a working volume of 400 litres. The systems were supplied fully assembled and included key performance and monitoring features such as peristaltic feed pumps, electrically heated jackets, gas-tight lids, and motorised agitators. Integrated instrumentation included real-time gas flow meters for methane (CH_4), carbon dioxide (CO_2), hydrogen sulphide (H_2S), and hydrogen (H_2), along with pH, pressure, and temperature sensors. These components were digitally controlled via a Programmable Logic Controller (PLC) and a Human Machine Interface (HMI), with SCADA-ready telemetry for future data integration and remote system management.

To verify functionality before shipment, a Factory Acceptance Test (FAT) was carried out on 4 July 2024 at UIT GmbH's Dresden facility. Representatives from Tessele Consultants attended and collaborated directly with the manufacturer's engineers to test the heating systems, confirm sensor calibration, validate PLC software, and inspect mechanical assemblies. Leak integrity was tested at 30 mbar for 14 hours to confirm gas-tightness. All systems performed to specification. The results were documented in detailed test logs, checklists, and a comprehensive photographic record, ensuring full transparency and traceability.

Following successful FAT validation, the digesters were shipped to Australia via sea freight—a decision made to reduce transport costs and environmental impact. The equipment arrived in Brisbane in November 2024 and was received at Griffith University's Nathan Campus, where it was temporarily stored in a secure indoor facility. Upon arrival, both units were carefully unpacked and inspected. All components were intact, and no signs of transport-related damage were observed. At this stage, the manufacturer's 12-month warranty was formally activated.

While initial plans included installation at Griffith University, multiple challenges—such as zoning restrictions, insufficient ventilation capacity, and a need for significant electrical and structural modifications—rendered the site unviable. This prompted the project team to reassess options and engage GPA Engineering to conduct a detailed Hazardous Area Classification (HAC) in line with AS/NZS IEC 60079.10.1:2022. This assessment concluded that, with appropriate vertical venting and engineering controls, the reactors could operate within a zone of negligible extent (NE), thereby simplifying compliance and enabling broader site flexibility.

In response to these site constraints, Tessele Consultants transitioned to an independent deployment model and established the Tessele Bio Hub, a purpose-designed R&Dfacility in Myaree, Western Australia. The warehouse was selected for its compatibility with all technical and regulatory needs, including access to three-phase power, adequate space for safe venting and bunding, and its proximity to Tessele's engineering and research team. Fit-out activities were carried out to prepare the site for installation, including the development of bunded containment zones, electrical provisioning, and preparation of vertical biogas vent stacks as specified in the HAC.

In early June 2025, the digesters were safely removed from Griffith University, transported to Perth, and delivered to the Tessele Bio Hub. The reactors are now staged within the facility, awaiting final mechanical positioning and electrical connection. All preparatory documentation has been completed, including commissioning checklists, standard operating procedures (SOPs), risk assessments, and safety management protocols. The project has also secured all zoning and compliance requirements necessary for the operational phase.

At the conclusion of this phase, the project has achieved commissioning readiness. The digesters are on-site, safety-verified, and supported by a fully equipped R&D environment. Wet commissioning—the next

critical step involving the introduction of live feedstocks and functional validation of performance — will commence under Stage 2 of the RACE for 2030 initiative. This strong methodological foundation ensures that future experimental trials can proceed with minimal technical risk and full compliance, offering industry stakeholders a high-confidence pathway toward the adoption of co-digestion solutions.

6.0 Results

The project has successfully delivered all outcomes required to achieve installation readiness for pilot-scale anaerobic co-digestion (AnCoD) trials in the red meat sector. This includes the procurement, verification, international transport, and interim deployment of two advanced 400-litre automated anaerobic digesters. The next stage will focus on their installation and wet commissioning at the newly established Tessele Bio Hub in Myaree, Western Australia.

A pivotal early outcome was the completion of the Factory Acceptance Test (FAT) on 4 July 2024 at the UIT GmbH manufacturing facility in Dresden, Germany. Tessele Consultants oversaw a full system validation, confirming heating performance, accurate sensor calibration, effective mixing, and safety system functionality, including alarms and emergency shutdowns. Each digester reliably reached and maintained mesophilic and thermophilic temperatures, and both passed airtightness verification via a 14-hour pressure integrity test. The FAT was comprehensively documented through checklists, operational logs, and photographic records, presented in pages 13 to 21 of the appended FAT report.

Following FAT approval, both digesters were shipped via sea freight to minimise costs and emissions. They arrived safely at Griffith University's Nathan campus in late November 2024, and a post-shipment inspection confirmed their integrity. As documented in Figures 1 and 2, the systems remained undamaged and were temporarily stored with protective coverings and signage in place. The manufacturer's 12-month equipment warranty was officially activated on 2 December 2024.

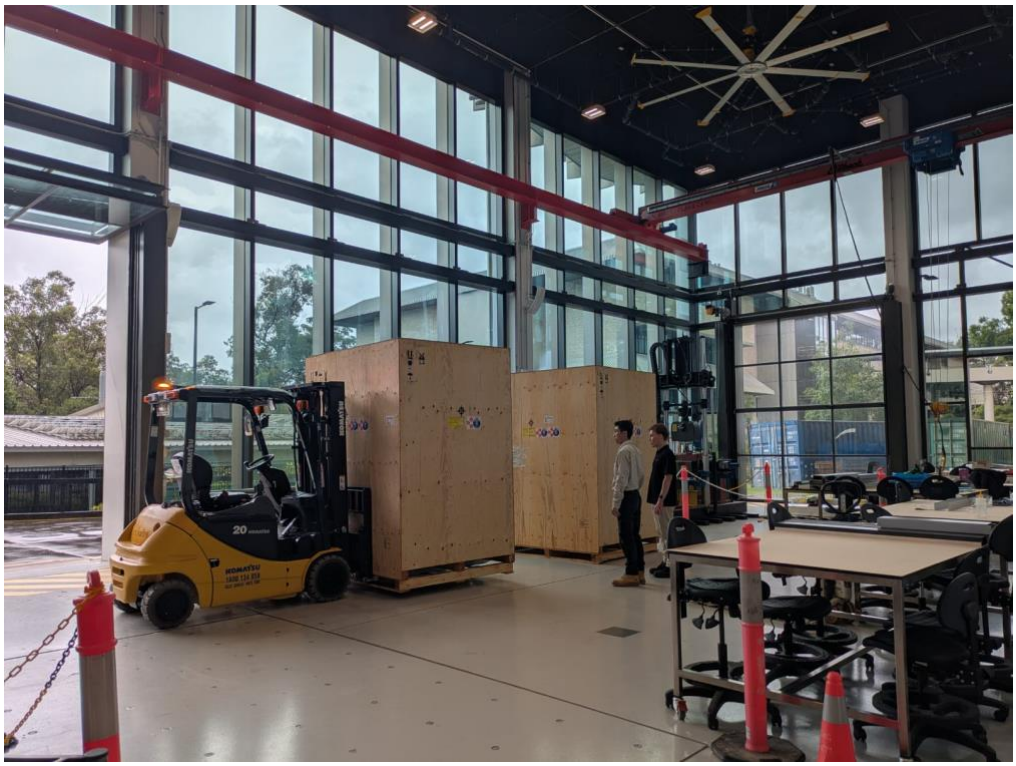

Figure 1 Reactors' arrival at Griffith University (22-11-24)

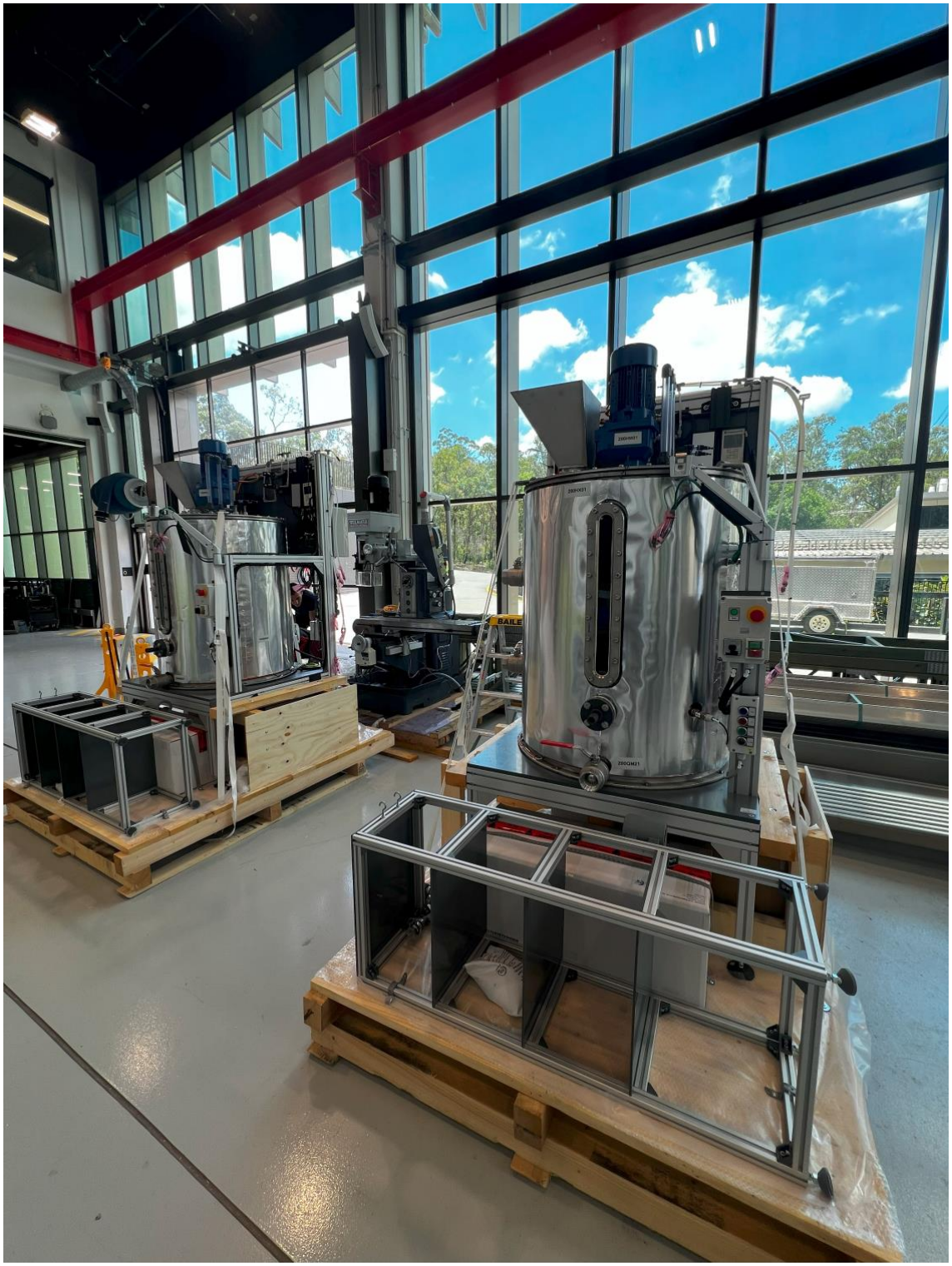

Figure 2 Unpacked reactors safely stored at Griffith University (Nathan campus).

However, due to unforeseen infrastructure constraints and escalating compliance requirements at the university, the project team redirected its deployment strategy. After further site investigations and unsuccessful negotiations with other research institutions, Tessele Consultants opted to develop an independent facility. This led to the establishment of the Tessele Bio Hub, a purpose-built R&D site in Myaree that meets zoning, electrical, and safety criteria, including vertical biogas venting, bunded containment, and access to three-phase power.

A key milestone and industry highlight was the stakeholder engagement workshop held on 26 March 2025 at Griffith University. This event marked the first public showcase of the pilot digesters and was attended by over 30 participants from across the red meat industry, government, academia, and the energy sector. Stakeholders were given the opportunity to inspect the units, learn about their capabilities, and explore their potential role in decarbonisation and circular economy initiatives. A professional video was produced by RACE for 2023 to commemorate the event and can be accessed via this link. Figure 3 report illustrates the enthusiasm generated by the workshop and the strength of industry engagement.

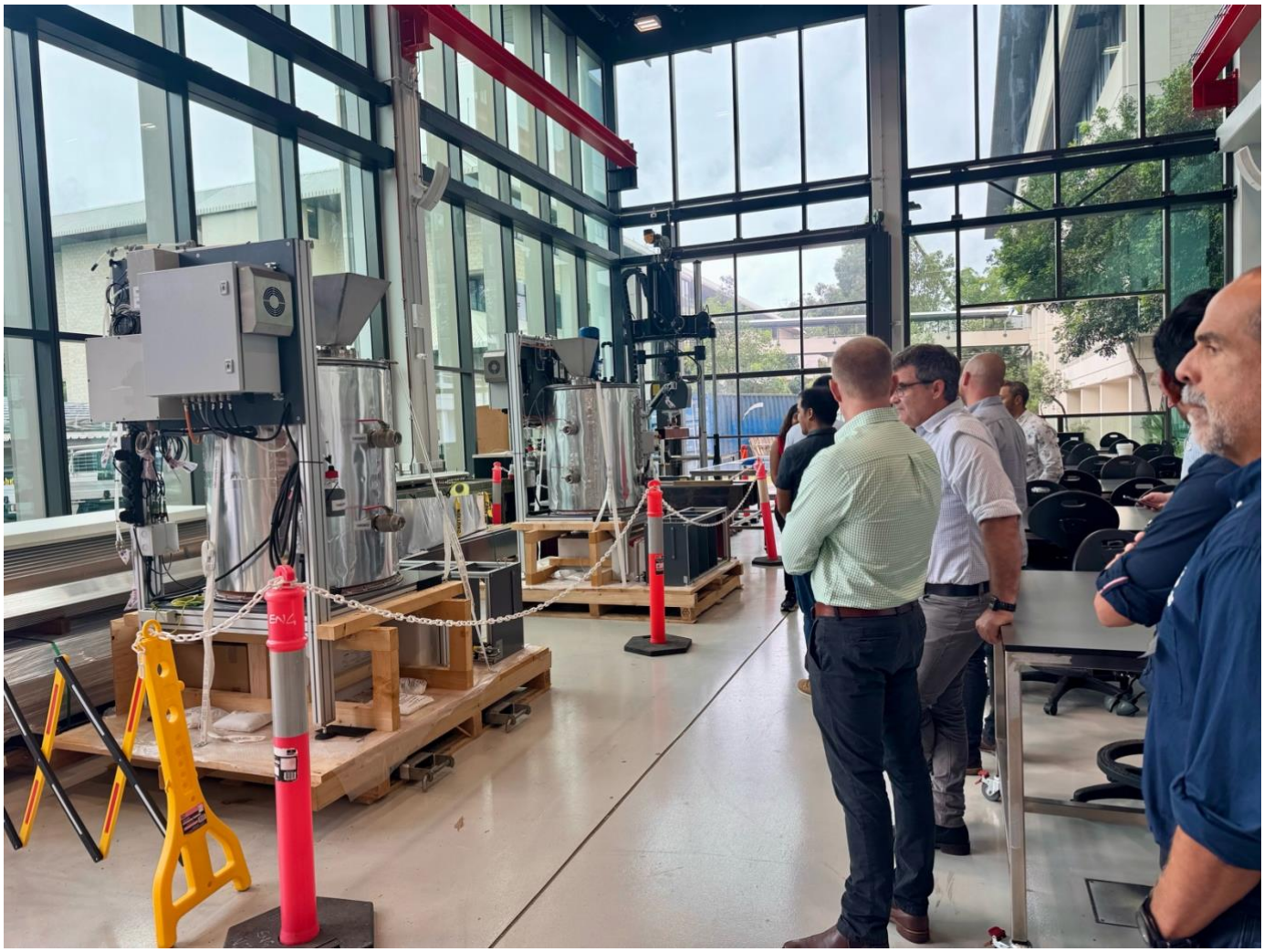

Figure 3 Reactors being displayed at the stakeholder workshop in March 2025.

In early June 2025, both digesters were safely decommissioned and transported to the Tessele Bio Hub. All necessary risk assessments were completed, and equipment was handled according to pre-established safety protocols. At the new facility, the digesters are now staged for final installation and wet commissioning, where operational systems will be tested using hot water before live feedstock is introduced.

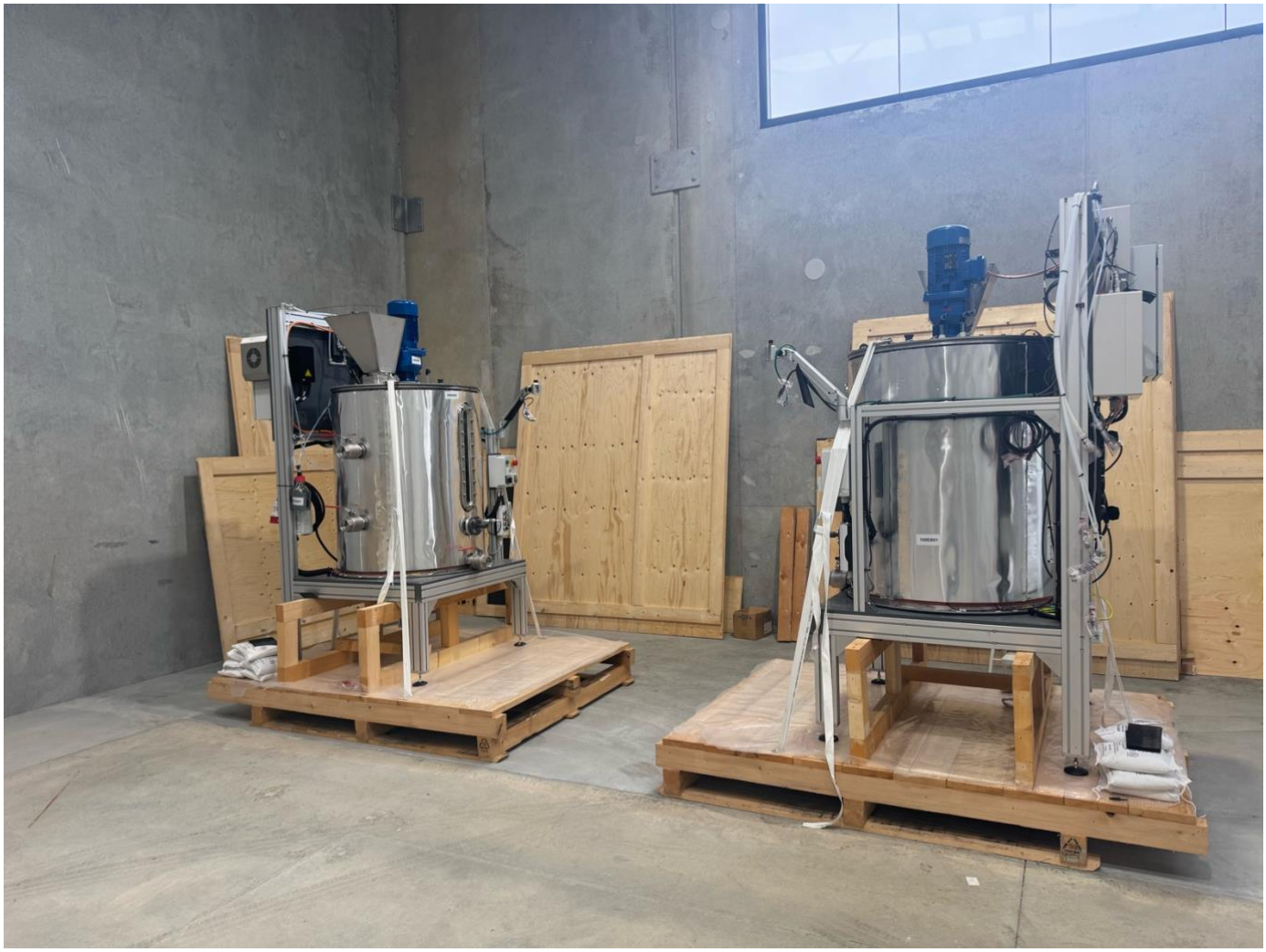

Figure 4. Reactors unpacked at Tessele Bio-Hub, ready for installation and wet commissioning.

To support future operations, the project team has also developed a full suite of standard operating procedures (SOPs), commissioning checklists, and safety plans. These resources ensure safe, repeatable, and compliant performance during the upcoming operational trials under the RACE Stage 2 digestate valorisation project.

In summary, the project has accomplished all deliverables required to progress into active commissioning and research. With the physical infrastructure in place, validated and relocated to a dedicated industry-aligned facility, the pilot-scale AnCoD platform is now ready to commence detailed biogas productivity and digestate quality investigations under controlled and scalable conditions.

7.0 Discussion

The results of this project represent a significant step forward in creating practical, low-risk opportunities for the red meat processing sector to engage with anaerobic co-digestion (AnCoD) technologies. By completing the procurement, validation, and delivery of two purpose-built pilot-scale anaerobic digesters—and resolving complex safety and infrastructure challenges through the establishment of the Tessele Bio Hub—the project has laid a critical foundation for real-world trials. These achievements provide a tangible, operationally relevant platform that can be used to test waste-to-energy strategies in a controlled, industry-aligned environment.

The successful completion of the Factory Acceptance Test (FAT) ensured that the equipment meets international standards for performance, automation, and safety. This is a key enabler of industry confidence. Processing businesses can be assured that the pilot units are not only technically sound, but also adaptable for use in varied operational settings. The presence of integrated biogas metering, remote monitoring capabilities, and automated feeding systems provides valuable data capture functions that are essential for understanding biogas yields, feedstock behaviour, and system optimisation. For businesses exploring capital investment in biogas infrastructure, this level of instrumentation offers a unique opportunity to de-risk decisions by simulating full-scale scenarios in a pilot environment.

Perhaps more importantly, the project has directly addressed one of the major adoption barriers previously identified in the sector: the lack of a fit-for-purpose testing platform. Unlike prior research, which was typically confined to laboratory settings or limited desktop studies, this initiative enables processing businesses to engage with AnCoD technology in a way that reflects the realities of site-specific waste characteristics, operational schedules, and compliance obligations. This practical orientation means that processors no longer have to rely solely on theoretical models—they now have a physical, accessible means of trialling solutions and building internal understanding.

The strategic pivot from university-hosted installations to an independent R&D facility was another key outcome. It revealed not only the institutional barriers that can slow innovation, but also the value of flexible, industry-led infrastructure. The creation of the Tessele Bio Hub has positioned the project for long-term relevance, offering a nationally available testbed for pilot-scale co-digestion trials. This facility can now be leveraged for future research partnerships, workforce training, regulatory testing, and processor demonstrations—greatly expanding the reach and impact of the original project.

For future or related research, the results suggest several clear directions. First, the availability of a stable pilot platform creates new opportunities to test a broader range of co-substrates, including various red meat processing wastes, agricultural residues, and food industry by-products. Second, the instrumentation installed within the reactors will allow high-resolution monitoring of process stability, gas quality, and system responsiveness, providing rich data to support model development and commercial feasibility assessments. Third, the project's documentation (including SOPs, risk management plans, and commissioning protocols) establishes a replicable framework that can be adapted by other sites or scaled for mobile deployment.

In short, this project has bridged the gap between research and application. It has turned the concept of co-digestion from an abstract opportunity into a practical, testable, and scalable reality for the red meat sector. The equipment is in place, the facility is ready, and the industry now has a credible, hands-on pathway to trial, adopt, and refine bioenergy solutions that align with its economic and environmental goals.

8.0 Conclusions

This project has successfully delivered the foundational infrastructure needed to accelerate the red meat industry's transition toward renewable energy generation through anaerobic co-digestion (AnCoD). By procuring, validating, and safely delivering two 400-litre pilot-scale digesters, and preparing them for commissioning at a dedicated research facility, the project has addressed critical technical and logistical barriers that have previously hindered the sector's ability to trial waste-to-energy solutions.

The comprehensive Factory Acceptance Test (FAT) demonstrated that the equipment meets all required operational and safety standards. The systems' advanced instrumentation and automation provide a high

level of control and data resolution, offering processors a realistic and reliable means of evaluating biogas performance under actual conditions. These capabilities ensure that trials conducted in the next phase will produce meaningful insights to guide future investment and system design.

The relocation of the project from a university-based model to the newly established Tessele Bio Hub in Myaree represents a strategic milestone. It reflects a shift toward industry-driven innovation and removes dependencies on institutional constraints that previously delayed implementation. This decision has resulted in the creation of a nationally significant, fit-for-purpose testing facility tailored to the needs of processors, researchers, and technology suppliers.

For processing businesses, the availability of a controlled and ready-to-operate pilot platform significantly reduces the risk of exploring AnCoD technologies. It allows for cost-effective, small-scale trials that can generate the operational data and staff experience needed to support future adoption at full scale. For researchers and industry stakeholders, the facility provides a credible environment for collaborative innovation, regulatory testing, and capacity building.

In conclusion, the project has achieved all objectives for Stage 1 and established a strong foundation for Stage 2 pilot trials. It has transformed the concept of co-digestion from theory to practice, and positioned the Australian red meat sector to lead in the development of circular, energy-efficient processing systems. With the reactors now on-site and commissioning preparations complete, the next step is to begin wet commissioning and data-driven exploration of co-digestion scenarios. This marks the beginning of a new phase of industry-aligned innovation, with the potential to deliver long-term environmental and economic benefits.

9.0 Recommendations

The successful delivery of two pilot-scale anaerobic co-digesters and the establishment of the Tessele Bio Hub mark a significant milestone in the red meat industry's capacity to evaluate and adopt anaerobic digestion (AD) technologies. With the equipment now on-site and commissioning readiness achieved, the next phase of work—under the **Pilot Biogas Reactor Installation and Wet Commissioning Project**—will involve final installation, system integration, and hot-water commissioning to validate performance under controlled conditions. These systems will then be used in the **RACE Stage 2 Digestate Valorisation Project**, positioning the facility as a national platform for both biogas optimisation and digestate product development.

Practical Application for Industry

Processors are strongly encouraged to engage with the Tessele Bio Hub once commissioning is complete. The facility will provide processors with access to a fit-for-purpose, shared infrastructure platform for testing site-specific combinations of organic waste and regional co-feedstocks. This service will support processors in understanding their potential for biogas generation, feedstock compatibility, and digestate characteristics before committing to costly infrastructure or full-scale design. The integration of digestate characterisation into future work will also allow processors to assess opportunities for nutrient recovery and the creation of compliant soil conditioners.

Future Research, Development, and Extension (RD&E)

The digesters are central to two critical next-stage RD&E efforts:

Pilot Biogas Reactor Wet Commissioning and Operation – This will finalise the mechanical, electrical, and instrumentation setup and begin baseline performance validation using clean water. It will confirm that all systems function as required and identify any residual bottlenecks prior to organic loading.

Digestate Valorisation (RACE Stage 2 Project) – Following operational commissioning, the digesters will be loaded with red meat processing wastes (e.g., DAF sludge, paunch, offal), co-digested with agricultural or food industry feedstocks. This project will evaluate:

- Digestate quality (nutrients, metals, pathogens);
- Dewatering performance and potential separation technologies;
- Application potential of treated digestate as a biofertiliser or soil conditioner, aligned with environmental regulations;
- Market and regulatory pathways for digestate reuse.

This combined research effort will not only demonstrate biogas yields but also address the critical challenge of digestate management, supporting processors in creating a closed-loop, resource-efficient waste strategy.

Adoption and Extension Activities

To accelerate industry uptake and awareness, the following activities are recommended:

Technical demonstration days and site tours at the Tessele Bio Hub, including walkthroughs of feedstock preparation, digester operation, and safety systems.

Industry briefings and case studies published during the Digestate Valorisation Project, focused on co-digestion feasibility, economic viability, and fertiliser potential.

Training and extension materials for processor staff, consultants, and regulators—covering AD system management, digestate handling, and relevant safety and compliance standards.

Integration with AMPC's extension network, enabling broader dissemination of project learnings through existing communications channels and R&D forums.

The digesters will become a long-term asset for the sector, enabling continuous testing of new waste streams and supporting strategic decision-making in areas such as emissions reduction, nutrient recovery, energy generation, and waste diversion. This infrastructure reduces risk and cost at the processor level and lays the groundwork for scalable AD adoption across the industry.

10.0 Project outputs

This project successfully delivered the foundational infrastructure and technical groundwork required to initiate pilot-scale anaerobic co-digestion (AnCoD) trials for the red meat industry. All outputs contributed toward creating a dedicated, compliant, and fully equipped testing facility at the Tessele Bio Hub in Myaree, Western Australia. The following deliverables were completed during the project period:

1. **Procurement and Validation of Pilot-Scale Equipment**

Two fully automated 400-litre anaerobic co-digestion reactors were procured from UIT GmbH in Dresden, Germany.

Factory Acceptance Test (FAT) was successfully completed on 4 July 2024, attended by Tessele Consultants (Fabiana Tessele and Kendall Ferraro).

FAT documentation included checklists, calibration records, operational validation, and photographic evidence.

2. **Safe Delivery and Warranty Activation**

Equipment was shipped internationally by sea freight and delivered to Griffith University in Brisbane in November 2024.

Post-arrival inspection confirmed no damage; manufacturer warranty activated as of 2 December 2024.

3. **Stakeholder Engagement – Industry Workshop**

Event: AMPC-RACE Stakeholder Workshop

Date: 26 March 2025

Location: Griffith University, Nathan Campus (Brisbane, QLD)

Attendees: ~35 participants, including red meat processors, RACE for 2030 representatives, researchers, consultants, and government stakeholders

Content: Showcase of pilot-scale reactors, demonstration of instrumentation and automation features, and facilitated discussions on AnCoD adoption pathways

Outcome: Strong industry interest in pilot testing opportunities and digestate management strategies

4. **Decommissioning and Relocation of Equipment**

Following limitations with institutional hosting, both reactors were safely decommissioned and relocated from Griffith University to the new Tessele Bio Hub facility in Myaree, WA in June 2025.

Transport and staging completed without incident; systems remain under warranty and in commissioning-ready condition.

7. **Industry Communications and Awareness**

Abstract Submitted to AMPC: A 250-word abstract summarising project objectives, outcomes, and industry benefits was submitted for publication in AMPC's processor newsletter and website.

Reach: Estimated audience of 2,000+ stakeholders across the Australian red meat supply chain.

Purpose: Raise awareness of the new facility and highlight opportunities for processors to engage in co-digestion trials.

8. Final Report (This Document)

Provides a full record of methodology, results, stakeholder engagement, and strategic context for future projects.

Includes recommendations for adoption, further RD&E, and integration into Stage 2 activities (i.e. RACE 2030 installation and digestate valorisation project).

11.0 Bibliography

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12.0 Appendices

12.1 Appendix 1

Factory acceptance test (see PDF attached)