Final Report

AMPC
AUSTRALIAN MEAT PROCESSOR CORPORATION

EU Technical Tour

EU Bioresource Recovery - Technology Update

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Germany's approach to renewable energy is characterised by a diverse and integrated strategy that leverages multiple sources, including solar, wind, biogas, and other renewables. The country has aggressively pursued the expansion of solar and wind energy, becoming a global leader in both sectors. Solar panels, widespread across rooftops and solar farms, contribute significantly to the national grid, especially during peak sunlight hours. Wind energy, both onshore and offshore, plays a crucial role in Germany's energy mix, with extensive wind farms dotting the landscape and the North Sea. Complementing these intermittent sources, biogas production from agricultural waste, organic matter, and sewage provides a reliable, continuous source of energy, aiding in grid stability and supporting the country's transition to a low-carbon economy. Additionally, Germany's focus on integrating these diverse energy sources through advanced grid management and energy storage solutions underscores its commitment to achieving a sustainable and resilient energy system. This holistic approach not only reduces reliance on fossil fuels but also drives innovation and economic growth within the renewable energy sector.

1 Executive Summary

1.1 Overview of the Project

The Australian red meat processing industry is at a critical juncture, facing mounting pressure to address environmental sustainability concerns while maintaining economic competitiveness. This project was initiated in response to the industry's pressing need to find innovative solutions that can reduce waste, lower greenhouse gas emissions, and enhance resource efficiency. The project's primary objectives were to assess the latest advancements in bioresources recovery technologies from the European Union (EU), evaluate their applicability within the Australian context, and provide actionable recommendations to the industry. The significance of this project lies in its potential to transform the environmental footprint of the Australian red meat processing sector, positioning it as a leader in sustainable practices.

The project involved an analysis of EU bioresources recovery technologies, with a focus on those showcased at the IFAT trade fair and through site visits facilitated by Evo Environmental Technologies. These technologies, including anaerobic digestion for biogas production, nutrient recovery processes, and the recovery of food-grade bioCO2 from biogas, were compared against current practices in the Australian red meat processing industry. The findings highlight significant opportunities for technology transfer and adaptation, with potential benefits including reduced waste, lower energy consumption, and new revenue streams from renewable energy and recycled by-products.

Key recommendations emerging from this study include prioritising the adoption of waste-to-energy technologies, developing industry-specific guidelines for integrating bioresources recovery technologies, and fostering collaboration between industry stakeholders to accelerate the adoption of these innovations. The high-level comparison of Australian and EU practices revealed gaps in the Australian industry's current approach, particularly in the areas of energy recovery and waste management, which could be addressed through the adoption of EU technologies.

1.2 Project Objectives and Approach

The project was guided by several key objectives:

1. Assessment of EU Bioresources Recovery Technologies: Evaluate the latest advancements in bioresources recovery technologies and their potential applicability to the Australian red meat processing industry.

2. Documentation of Case Studies and Best Practices: Compile detailed case studies from the EU, highlighting successful implementations and their operational, environmental, and economic outcomes.

3. Comparative Analysis: Compare current Australian red meat processing practices with those observed in the EU to identify gaps, opportunities, and potential for technology transfer or adaptation.

4. Exploration of Renewable Resource Opportunities: Investigate the potential for biogas, biomethane, and bioCO2 production in Australia, assessing technical feasibility, environmental benefits, and economic viability.

5. Industry Insights: Gather perspectives from Australian food processors on the benefits, challenges, and implementation experiences of bioresources recovery technologies.

6. Evaluation of Business Models and Technology Adaptations: Analyse innovative business models that could facilitate the adoption of sustainable technologies by Australian red meat processors.

7. Development of Actionable Recommendations: Provide clear, actionable recommendations for leveraging EU bioresources recovery technologies to enhance sustainability, efficiency, and profitability in the Australian red meat processing sector.

The project approach included an in-depth review of EU technologies, site visits facilitated by Evo Environmental Technologies, and interviews with Australian industry stakeholders. This methodology ensured a robust and comprehensive assessment of the potential for technology transfer and adaptation.

1.3 Project Outcomes and Insights

The project yielded several significant outcomes and insights that can benefit both members of the Australian red meat processing industry and the wider sector:

- Technological Advancements: EU bioresources recovery technologies, particularly in waste-to-energy conversion and nutrient recovery, offer substantial environmental and economic benefits. Their adoption in Australia could lead to reduced greenhouse gas emissions, lower operational costs, and enhanced resource efficiency.

- Operational and Economic Viability: Case studies from the EU demonstrated the economic viability of these technologies, with many processors achieving significant cost savings and generating new revenue streams through resource recovery.

- Comparative Analysis: The comparison of Australian and EU practices revealed that Australia lags in the adoption of advanced technologies, particularly in energy recovery and waste management. This presents an opportunity for the industry to close the gap and enhance its sustainability credentials.

- Industry Perspectives: Interviews with Australian food processors highlighted both the interest in and the challenges of adopting bioresources recovery technologies. Key concerns include the initial investment costs and the complexity of integrating new technologies into existing operations.

1.4 Conclusions and Recommendations

The conclusions of this project emphasise the substantial potential for the Australian red meat processing industry to improve its environmental performance through the adoption of EU bioresources recovery technologies. The key recommendations for industry stakeholders include:

- Prioritising Waste-to-Energy Technologies: Focus on adopting technologies that convert waste into renewable energy, thereby reducing emissions and operational costs.

- Developing Industry-Specific Guidelines: Establish clear guidelines and best practices for the integration of bioresources recovery technologies, tailored to the needs of the Australian industry.

- Fostering Collaboration: Encourage partnerships between industry stakeholders, including public-private collaborations, to facilitate the adoption of innovative technologies.

- Supporting Knowledge Sharing: Increase awareness and understanding of bioresources recovery technologies through targeted engagement initiatives, training programmes, and dissemination of success stories.

Recommendations for Further Research/Actions

To build on the findings of this project, further research should be conducted to explore the specific technical and economic challenges of adapting EU technologies to the Australian context. Additionally, pilot projects should be initiated to test the feasibility of these technologies in real-world Australian processing environments. Finally, continued collaboration between Australian and EU stakeholders will be essential in ensuring that the Australian red meat processing industry can fully capitalise on the opportunities presented by bioresources recovery technologies.

Project Results and Findings

The findings from this project provide valuable insights that can benefit not only members of the Australian red meat processing industry but also the wider sector. By adopting the recommendations outlined in this report, Australian processors have the opportunity to transform their environmental footprint, improve operational efficiency, and enhance their competitive position in a global market increasingly focused on sustainability. This transition will not only meet regulatory and consumer demands but also position the Australian red meat processing industry as a leader in environmental stewardship.

2 Introduction

The Australian red meat processing industry is at a pivotal moment, facing growing pressures to enhance its environmental sustainability. These pressures stem from increasingly stringent regulatory requirements and a shift in consumer expectations towards more eco-friendly practices. Historically, the industry has encountered significant challenges in managing waste and emissions, which have resulted in environmental degradation and heightened scrutiny from both regulatory bodies and the public. In response to these challenges, this research project was initiated to explore innovative solutions that could mitigate the environmental impact of red meat processing while simultaneously improving operational efficiency and profitability.

The primary purpose of this research project is to assess the applicability of advanced bioresources recovery technologies, particularly those developed and successfully implemented in the European Union (EU), within the Australian red meat processing industry. The EU has been a global leader in adopting cutting-edge environmental technologies, driven by its strict regulatory framework and a strong commitment to sustainability. These technologies, which include anaerobic digestion for biogas production, nutrient recovery systems, and the recovery of food-grade bioCO2 from biogas, have the potential to transform waste and emissions into valuable resources.

This project builds on previous research and technological advancements in the field of bioresources recovery. Prior studies have highlighted the benefits of such technologies in reducing greenhouse gas emissions, lowering energy consumption, and creating new revenue streams through the sale of renewable energy and recycled by-products. However, the specific applicability of these technologies to the Australian context, particularly within the red meat processing industry, has not been thoroughly investigated. This research seeks to fill that gap by conducting an analysis of EU bioresources recovery technologies and evaluating their potential for adaptation and implementation in Australia.

The scope of the research encompasses a detailed evaluation of the latest bioresources recovery technologies, with a particular focus on those showcased at the IFAT trade fair and through site visits facilitated by Evo Environmental Technologies. The project also includes the documentation of successful case studies from the EU, a comparative analysis of current practices in Australia and the EU, and an exploration of the potential for renewable resource opportunities, such as biogas, biomethane, and food-grade bioCO2 production. Additionally, insights gathered from interviews with Australian food processors who have been exposed to these technologies will provide a deeper understanding of the practical challenges and benefits associated with their adoption.

By examining the potential for technology transfer and adaptation, this research aims to provide actionable recommendations that can guide the Australian red meat processing industry towards a more sustainable and economically viable future. The outcomes of this project are expected to contribute to the broader industry knowledge, offering insights that could be applied not only within the red meat processing sector but also across other industries facing similar environmental challenges.

3 Project Objectives

• Assess EU Bioresources Recovery Technologies: Evaluate the latest advancements in bioresources recovery technologies showcased at the IFAT trade fair and through Evo Environmental Technologies visits to understand their applicability to the Australian red meat processing industry.

• Document Case Studies and Best Practices: Compile detailed case studies from the EU, highlighting successful implementations of bioresources recovery technologies, focusing on operational, environmental, and economic outcomes.

• Conduct Comparative Analysis: Compare current Australian red meat processing practices with those observed in the EU to identify gaps, opportunities, and potential for technology transfer or adaptation.

• Explore Renewable Resource Opportunities: Investigate the potential for biogas, biomethane, and bioCO2 production within the Australian context, assessing technical feasibility, environmental benefits, and economic viability.

• Gather Industry Insights: Interview Australian food processors present at IFAT or during Evo ET visits to capture their perspectives on bioresources recovery technologies, including benefits, challenges, and implementation experiences.

• Evaluate Business Models and Technology Adaptations: Analyse innovative business models and adaptations that could facilitate the adoption of sustainable bioresources recovery technologies by Australian red meat processors.

• Develop Actionable Recommendations: Provide clear, actionable recommendations for the Australian red meat processing sector on leveraging EU bioresources recovery technologies to enhance sustainability, efficiency, and profitability.

• Enhance Industry Knowledge and Awareness: Increase awareness and understanding within the Australian red meat processing industry of the benefits and opportunities presented by adopting advanced bioresources recovery technologies.

4 Methodology

Project Initiation: The project began with a planning phase designed to ensure the successful execution of site visits, stakeholder engagements, and data collection activities. This phase involved developing a detailed itinerary, making travel and accommodation arrangements, and setting up meetings with relevant stakeholders. The itinerary was carefully crafted to include key events such as the IFAT trade fair and site visits to Evo Environmental Technologies (Evo ET). The planning process also involved the identification of critical technologies and sites for review, ensuring comprehensive coverage of relevant bioresources recovery innovations.

Research and Data Collection: The research and data collection phase was structured to gather both qualitative and quantitative data. The project team attended the IFAT trade fair, where they conducted observational research, taking detailed notes on the latest advancements in bioresources recovery technologies. This included documenting the technical specifications, operational efficiencies, and environmental benefits of various technologies. Following the trade fair, the team conducted site visits to Evo ET facilities, where they observed real-world applications of these technologies. During these visits, measurements were taken to assess the performance of specific technologies, including their energy consumption, waste reduction capabilities, and greenhouse gas emissions. These measurements were recorded systematically to facilitate later analysis.

Stakeholder Engagement: Stakeholder engagement was a crucial part of the methodology, designed to gather industry insights directly from Australian red meat processors. The project team conducted semi-structured interviews with key industry stakeholders, focusing on their experiences with waste management, resource recovery, and their perspectives on adopting new technologies. The interview data were transcribed and coded for thematic analysis, allowing the team to identify common challenges, opportunities, and attitudes towards bioresources recovery technologies. This qualitative data provided context to the quantitative findings and informed the overall analysis.

Comparative Analysis: The comparative analysis was designed to evaluate the current practices within the Australian red meat processing industry against the advanced bioresources recovery technologies observed in the EU. This analysis involved comparing key performance indicators (KPIs) such as waste reduction efficiency, energy consumption, greenhouse gas emissions, and overall cost-effectiveness. The project team employed statistical methods to analyse the data, including descriptive statistics to summarise the performance of each technology and inferential statistics to determine the significance of differences between Australian practices and EU technologies. This analysis helped to identify gaps in current practices and highlight areas where EU technologies could offer improvements.

Business Model Analysis: In addition to the technical analysis, the project included an exploration of business models suitable for the adoption of bioresources recovery technologies in Australia. The team analysed the economic viability of these technologies by considering factors such as implementation costs, potential savings, revenue generation from renewable energy and recycled products, and the scalability of the technologies for different sizes of operations. Sensitivity analysis was conducted to evaluate the financial risks and benefits under various market conditions, providing an assessment of the business case for adopting these technologies in the Australian context.

Development of Recommendations: Based on the findings from the comparative and business model analyses, the project team developed a set of actionable recommendations. These recommendations were formulated using a systematic approach that considered the feasibility, impact, and practicality of each suggested action. The recommendations were designed to guide industry stakeholders in adopting bioresources recovery technologies, with a focus on improving environmental performance, reducing operational costs, and creating new revenue streams. The recommendations were also validated through feedback from industry stakeholders to ensure their relevance and applicability.

Dissemination and Outreach: The final phase of the project focused on disseminating the findings and recommendations to the broader industry. The project team prepared an final report, detailing the methodologies, analyses, and outcomes of the research. In addition, the team organised a webinar to present key insights and engage with industry stakeholders. The dissemination strategy also included publishing the findings in industry journals and collaborating with industry associations to maximise the reach of the project outcomes. The goal of these activities was to raise awareness of the potential benefits of bioresources recovery technologies and to encourage their adoption across the Australian red meat processing industry.

This methodological approach, combining qualitative and quantitative research, thorough statistical analysis, and strategic stakeholder engagement, ensured that the project's findings were robust, actionable, and relevant to the industry's needs.

5 Project Outcomes

The EU technical visits organised by Evo Energy Technologies attracted a diverse group of industries, each with a vested interest in the latest advancements in bioresources recovery and sustainability technologies. Attendees included biogas plant operators seeking to optimise energy production from organic waste, and waste management companies focused on innovative solutions for resource recovery and environmental compliance. Engineering firms participated to explore cutting-edge technologies for wastewater treatment and energy efficiency, while representatives from the food and beverage industry were keen on the potential applications of CO_2 recovery systems and nutrient recycling. Additionally, professionals from both white and red meat processing sectors attended, aiming to enhance their operations with sustainable practices that reduce waste and improve energy utilisation, aligning with the industry's growing commitment to carbon neutrality and resource efficiency.

5.1 Site visits organised by EVO Energy Technologies

5.1.1 ETW Factory

As part of the research project, the group conducted a visit to the ETW manufacturing facilities, which provided an overview of the company's capabilities in the production of advanced biomethane technologies. The factory tour was designed to give an in-depth understanding of the manufacturing processes, the scale of operations, and the specific technologies being developed for various markets, including the USA and Europe.

During the tour, the team observed several large biomethane projects currently in production, primarily intended for the USA market. These projects are focused on landfill applications, showcasing ETW's expertise in converting landfill gas into biomethane, a renewable energy source. The scale of these projects highlighted ETW's ability to handle large volumes of gas and their proficiency in delivering solutions tailored to the demands of the American market, which has specific regulatory and operational requirements for landfill gas management.

In addition to the landfill-based biomethane projects, the team also observed a distinctive biomethane project that included a Food Grade CO2 recovery plant. This project demonstrated ETW's capability to not only produce biomethane but also to recover high-purity carbon dioxide suitable for food industry applications. The integration of CO2 recovery with biomethane production represents a significant advancement in resource efficiency, as it enables the utilisation of by-products that would otherwise be wasted. This technology is particularly relevant for industries that require large quantities of food-grade CO_2, such as beverage production and food processing.

The visit to ETW provided valuable insights into the latest advancements in biomethane technology and the potential for integrating CO_2 recovery into these processes. The observations from this tour will inform the broader analysis of how similar technologies could be applied within the Australian red meat processing industry, particularly in enhancing sustainability and creating additional revenue streams through resource recovery.

Figure 1. Images from the ETW manufacturing facilities, focused on biogas upgrade and liquid CO_2 recovery.

5.1.2 Domestic Wastewater Treatment Plant in Cologne – Germany.

As part of the research project, the group visited a state-of-the-art wastewater treatment plant in Cologne, which provided an in-depth look at advanced biogas-to-biomethane conversion technologies. This facility, installed in 2022, is a significant example of how wastewater treatment processes can be integrated with renewable energy production.

Figure 2. Images of the biogas and bioCO2 production from wastewater, located in Koln.

The plant features a sophisticated system capable of producing 480 cubic metres of biomethane per hour from biogas generated on-site. This high-output facility demonstrates the potential for wastewater treatment plants to contribute to the renewable energy supply, reducing reliance on fossil fuels and lowering greenhouse gas emissions. The biomethane produced is of high purity and is likely injected into the local gas grid, supporting the region's energy needs with a sustainable alternative.

However, the visit also highlighted a current gap in the plant's operations: the waste CO2 generated during the biomethane production process is not yet being utilised. Despite the advanced nature of the plant's biogas upgrading system, which efficiently converts biogas to biomethane, the carbon dioxide by-product is not captured or repurposed. This represents a missed opportunity for resource recovery, particularly given the growing demand for food-grade CO2 in various industries.

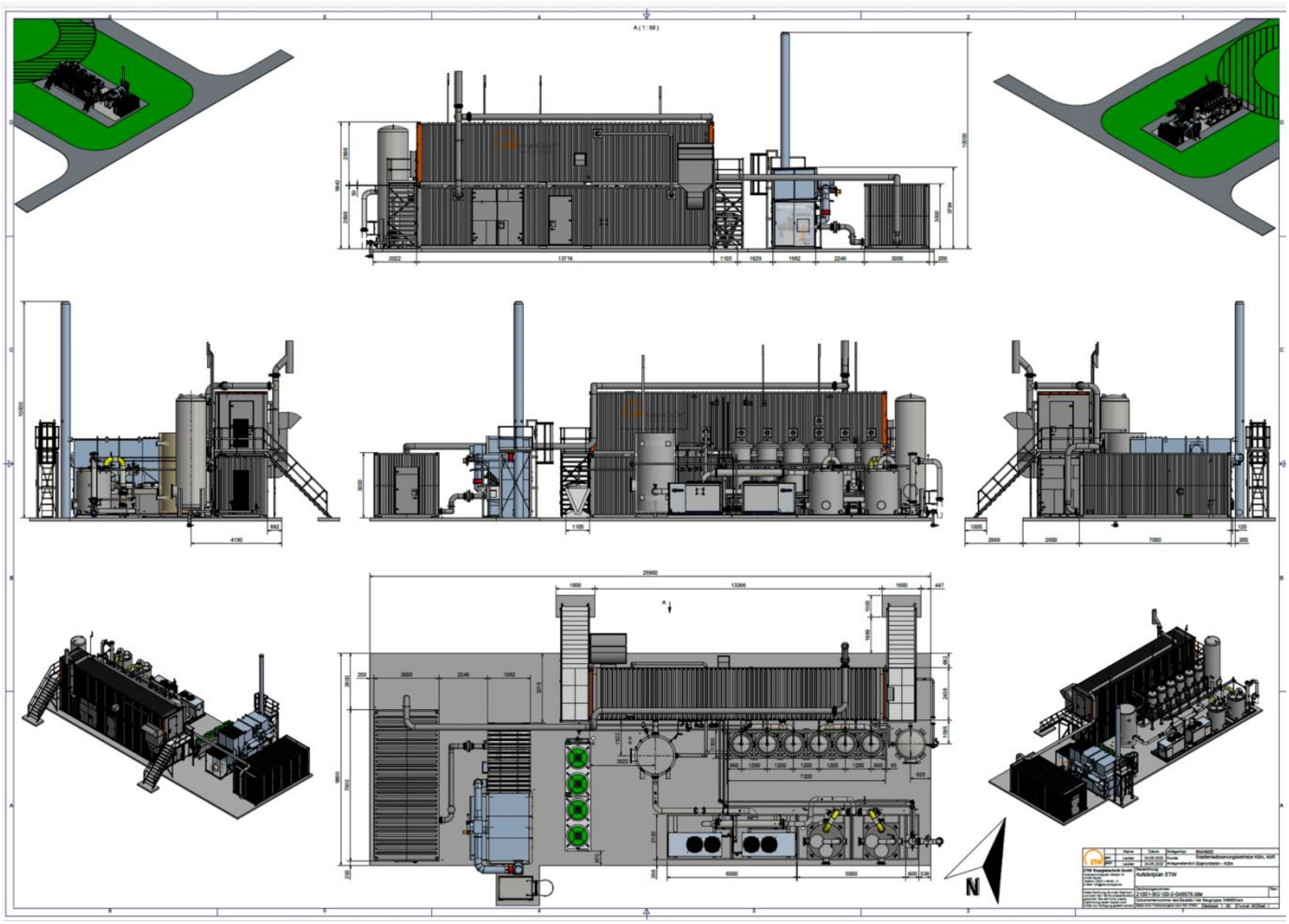

Figure 3. 3D drawings of the bioCO2 production from wastewater biogas, located in Koln

The plant's potential for integrating CO2 recovery technologies could significantly enhance its overall efficiency and sustainability. Capturing and utilising the waste CO2 could provide additional revenue streams, reduce the plant's carbon footprint, and align with broader environmental goals. The insights gained from this visit will contribute to the project's exploration of how similar technologies could be applied or improved upon within the Australian red meat processing industry, particularly in integrating CO2 recovery with biomethane production.

	Biogas vor Konditionierung		Biogas nach Konditionierung		Biomethan		CO2 reiches Schwachgas	
	Vol %	Nm^3/h	Vol %	Nm^3/h	Vol %	Nm^3/h	Vol %	Nm^3/h
CH_4	61,00	488,00	61,00	488,00	95,00	478,24	3,29	9,76
CO_2	38,40	307,20	38,40	307,20	4,28	21,53	96,32	285,67
H_2O	-	-	-	-	Taupunkt < 65°C	-	-	-
N_2	0,50	4,00	0,50	4,00	0,68	3,40	0,20	0,60
O_2	0,10	0,80	0,10	0,80	0,05	0,24	0,19	0,56
H_2S	50 ppm	61,4 g/h	< 3ppm	-	-	-	-	-
Nennlast	100%	800,00		800,00		503,41		296,59
Temperatur	15°C		5°C		25°C		40°C	
Druck	0,003 bar g		0,09 bar g		3 bar g		0,05 bar g	
Brennwert Hs	6,75 kWh/Nm^3		6,75 kWh/Nm^3		10,51 kWh/Nm^3		0,36 kWh/Nm^3	
Wobbeindex	6,99 kWh/Nm^3		6,99 kWh/Nm^3		13,57 kWh/Nm^3		0,30 kWh/Nm^3	
Kondensat			0,00 l/h					
Leistungsaufnahme und Energieverbrauch: Konditionierung + ETW SmartCycle® PSA					149 kW 0,186 kWh/Nm^3 Roh-Biogas			

Theoretische hydraulische Verarbeitungskapazität (Biogas) der Anlage*:

Min. Last	160 Nm^3/h	20%
Max. last	800 Nm^3/h	100%

* Roh-Biogas Temperatur: 15°C

Theoretische Produktionskapazität (Biomethan) der Anlage **:

Min. prod. Kapazität	101 Nm^3/h
Max prod. Kapazität	503 Nm^3/h

** CH4 Konzentration im Biogas: 61,00 Vol.-%

Figure 4. Biomethane and bioCO_2 production details, located in Koln.

5.1.3 Peaking Plant Duisburg, Germany (30MW Cogeneration)

As part of the research project, the group visited a large 30MW cogeneration peaking plant owned by a local power utility. This facility provided a remarkable example of how legacy infrastructure can be repurposed to meet modern energy demands while enhancing efficiency and sustainability.

The cogeneration plant is situated within a former coal turbine hall, which has been repurposed to house nine gas cogeneration units, each with a capacity of 4.3MW, resulting in a total installed capacity of approximately 30MW. The three-storey-high installation highlights the scale and complexity of the operation, showcasing the utility's commitment to transitioning from coal-based power generation to more sustainable energy solutions.

This plant plays a crucial role in the local energy landscape, producing both electricity and hot water for the local central heating grid. The cogeneration units are designed to operate as a peaking plant, meaning they can be quickly ramped up to meet sudden spikes in electricity demand, thereby enhancing grid stability and reliability. The hot water generated as a by-product of electricity production is efficiently utilised to supply the local district heating system, ensuring that energy is used as efficiently as possible.

In addition to the cogeneration units, the facility also features a 30MW electrode boiler. This innovative component allows the plant to utilise excess renewable energy, such as surplus electricity from wind or solar sources, to produce heat that can be stored and later distributed through the heating grid. This capability not only helps in balancing the grid by absorbing excess renewable energy but also contributes to the overall sustainability of the energy system by ensuring that no renewable energy is wasted.

Figure 5. Peaking Cogeneration Plant Duisburg, Germany.

The visit to this cogeneration peaking plant underscored the potential for integrating modern energy technologies into existing infrastructure. The plant's ability to produce both electricity and heat, combined with its use of an electrode boiler for renewable energy storage, presents a model of efficient and flexible energy production. These insights are valuable for the Australian context, particularly in exploring how similar cogeneration and energy storage technologies could be applied within industries like red meat processing, where both energy efficiency and sustainability are increasingly important.

5.1.4 2G Factory – Heek, Germany

As part of the research project, the group visited the 2G factory, a leading manufacturer of combined heat and power (CHP) systems. This visit provided an in-depth look at the latest advancements in cogeneration technology, with a particular focus on the assembly of cutting-edge 100% hydrogen cogeneration units, as well as various biogas and natural gas CHP plants currently in production.

During the factory tour, the team observed the assembly process of several 100% hydrogen cogeneration units. These units represent the forefront of sustainable energy technology, capable of generating both heat and power without producing carbon emissions, as hydrogen combustion only releases water as a by-product. The assembly of these units showcased 2G's commitment to innovation and their readiness to support the transition to a hydrogen-based energy economy. The team gained valuable insights into the technical complexities involved in designing and manufacturing these advanced systems, which are poised to play a crucial role in the future of clean energy.

Figure 6. 2G Factory Tour in Heek, Germany.

In addition to the hydrogen units, the factory was bustling with the production of various biogas and natural gas CHP plants. These systems are integral to the current energy landscape, offering efficient and flexible solutions for producing heat and power from renewable and conventional gas sources. The diversity of the production lines underscored 2G's capacity to cater to different energy needs and their adaptability in meeting the evolving demands of the global energy market.

The visit also included a tour of 2G's service department and remote monitoring divisions. The service department is responsible for the maintenance and support of 2G's installed units worldwide, ensuring their optimal performance and longevity. The remote monitoring division, on the other hand, provides continuous oversight of operational CHP units, enabling real-time diagnostics and predictive maintenance. This capability is crucial for maintaining high levels of efficiency and reliability across the fleet of 2G units, minimising downtime, and reducing operational costs for clients.

> *"Emerging energy and waste management technologies are poised to transform Australia's sustainability landscape, offering substantial opportunities to reduce greenhouse gas emissions and enhance energy security."*
> *Travis McNeil, Evo ET*

The insights gained from the 2G factory visit were significant, particularly in understanding the latest technological advancements in cogeneration and the practical aspects of maintaining and optimising these systems. The focus on 100% hydrogen cogeneration units highlights the potential for integrating these technologies into future energy systems, including within the Australian context, where there is growing interest in hydrogen as a clean energy source. The comprehensive service and monitoring capabilities observed also suggest a model for how these technologies can be supported and sustained over the long term, ensuring their successful deployment and operation.

5.1.5 Biolesker Bioladen Biogas Plant

As part of the research project, the group visited the Biolesker Bioladen biogas plant located at Heideweg 22, 48703 Stadtlohn, Germany. This facility provided valuable insights into the practical application of biogas technology, particularly in the use of agricultural residues for energy production.

The biogas plant at Biolesker Bioladen primarily utilises crop residue and cow manure as feedstock, demonstrating a sustainable approach to managing agricultural waste while generating renewable energy. The plant features two key combined heat and power (CHP) units:

1. Avus 1000plus 1000kW Biogas CHP: This larger unit is central to the plant's operations, converting biogas derived from the anaerobic digestion of crop residue and manure into electricity and heat. The Avus 1000plus, with its 1000kW capacity, is highly efficient, producing significant amounts of energy that can be fed into the local grid or used onsite to support the plant's operations.

2. Agenitor 406 250kW CHP: Complementing the larger unit, the Agenitor 406 is a 250kW CHP system that provides additional flexibility and energy generation capacity. This smaller unit is particularly valuable for balancing energy production and ensuring consistent output, even when feedstock availability or biogas production fluctuates.

The plant's use of locally sourced agricultural waste highlights the potential for biogas facilities to contribute to both waste management and renewable energy production. By converting crop residue and cow manure into biogas, Biolesker Bioladen not only reduces the environmental impact of these waste materials but also creates a valuable energy resource that supports local energy needs.

The visit to Biolesker Bioladen demonstrated the practical application of biogas technology in an agricultural setting, offering a model that could be adapted to similar contexts in other regions, including Australia. The insights gained from this visit will inform the broader analysis of how biogas technologies can be effectively integrated into agricultural and industrial operations to enhance sustainability and energy efficiency.

5.1.6 Biomethane Facility on Family Farm

As part of the research project, the group visited a biomethane facility located on a family farm at 75 Chemin de la Pierre, 26750 Geyssans, France. This site provided a clear example of how small-scale agricultural operations can contribute to renewable energy production through the use of biomethane technology.

Figure 7. Biodigesters and BioCO_2 recovery from agricultural residues and cow manure as feedstock in France.

The facility primarily utilises agricultural residues and cow manure as feedstock, reflecting a sustainable approach to waste management while simultaneously generating clean energy. The anaerobic digestion process at this facility converts the organic material into biogas, which is then upgraded to biomethane.

The biomethane facility has an output capacity of 80 cubic metres per hour, which is directly injected into the local gas grid. This integration into the local energy infrastructure demonstrates the practical and economic viability of small-scale biomethane production, particularly in rural areas where agricultural waste is readily available. The injection of biomethane into the gas grid not only provides a renewable energy source for the community but also contributes to reducing the carbon footprint associated with fossil fuel consumption.

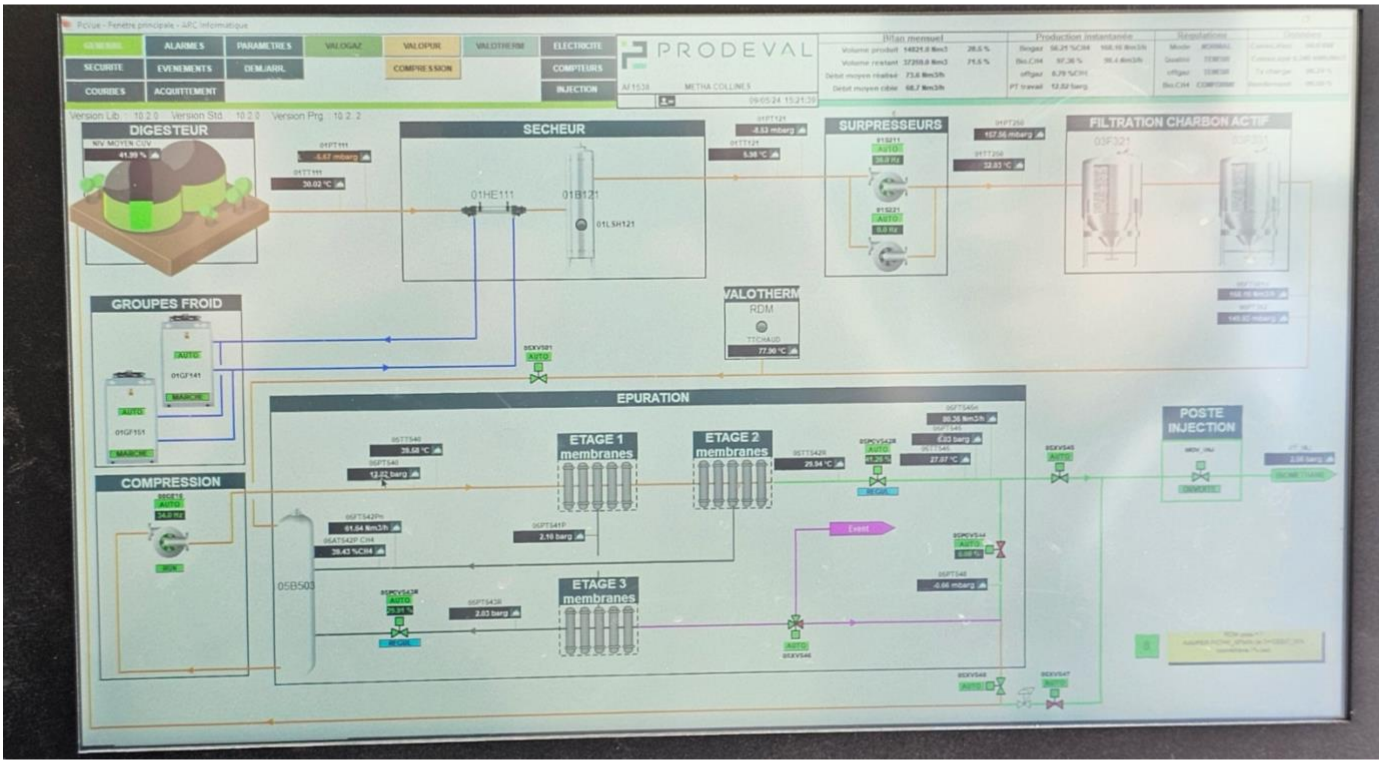

Figure 8. Screenshot with the process flow diagram at the Biodigesters and BioCO$_2$ recovery from agricultural residues and cow manure as feedstock in France.

This visit showcased the potential for family-run farms to diversify their income streams through the production of renewable energy while simultaneously addressing waste management challenges. The facility's ability to produce and supply biomethane to the local grid highlights the scalability and adaptability of this technology for small to medium-sized agricultural operations.

The insights gained from this visit are particularly relevant for considering how similar biomethane production models could be implemented in other agricultural settings, including within the Australian context. By leveraging locally available resources, such facilities can play a crucial role in enhancing energy security, reducing greenhouse gas emissions, and promoting sustainable farming practices.

5.1.7 Biomethane Facility at Food Waste Receival Facility

As part of the research project, the group visited a biomethane production facility located at a food waste receival site on Chemin des Caires, 26800 Étoile-sur-Rhône, France. This facility provided an insightful look into the transformation of organic waste into renewable energy, specifically focusing on the conversion of food waste into biomethane.

The facility currently processes large quantities of food waste, converting it into biogas through anaerobic digestion. This biogas is then upgraded to produce biomethane, with an impressive output capacity of 200 cubic metres per hour. The biomethane is injected into the local gas grid, providing a sustainable and renewable energy source to the surrounding community. This operation highlights the efficiency and potential of food waste as a feedstock for renewable energy production, turning a challenging waste stream into a valuable resource.

Figure 9. Biomethane Facility at Food Waste Receival Facility.

One of the most exciting developments at this facility is the planned addition of a food-grade CO2 recovery system, slated for early 2025. This future upgrade will allow the facility to capture and purify the CO2 produced during the biomethane upgrading process. The recovered CO_2 will meet food-grade standards, making it suitable for various applications in the food and beverage industry. This enhancement not only increases the facility's sustainability by utilising a by-product that would otherwise be released into the atmosphere but also opens up new revenue streams through the sale of food-grade CO2.

The visit to this biomethane facility underscored the growing potential of food waste as a critical feedstock for renewable energy production. The integration of a CO2 recovery system further enhances the facility's environmental and economic impact, demonstrating an approach to waste management and resource recovery.

The insights gained from this visit will be valuable in considering how similar technologies and processes can be applied in other regions, including Australia, where food waste management and renewable energy production are increasingly important. The planned CO2 recovery system also offers a model for maximising the value of by-products in biogas production, contributing to both sustainability and profitability.

5.1.8 Prodeval Facility

As part of the research project, the group visited the Prodeval facility located at Staub Rovaltain, Parc du 45ème Parallèle, 7 rue Anne-Marie, 26300 Châteauneuf-sur-Isère, France. This visit offered an overview of Prodeval's advanced biogas upgrading technologies and their state-of-the-art monitoring and control systems.

Figure 10. Prodeval facility located at Staub Rovaltain, Châteauneuf-sur-Isère, France

One of the key highlights of the visit was the demonstration of Prodeval's 24/7 remote monitoring capabilities. All sites equipped with Prodeval technologies are continuously monitored to ensure optimal performance and to quickly address any operational issues. The system is designed to detect faults or anomalies in real-time, allowing for an incredibly fast response time of just 5 minutes. This rapid response capability is critical in minimising downtime and ensuring the consistent and efficient operation of biogas plants.

The remote monitoring system is a testament to Prodeval's commitment to maintaining high standards of reliability and efficiency across their installations. The ability to monitor and respond to issues from a central location not only enhances the operational efficiency of the plants but also provides peace of mind to operators, knowing that any potential problems can be swiftly addressed.

During the tour, the team observed the central control room where the monitoring takes place. The room was equipped with advanced diagnostic tools and real-time data feeds from various sites. This setup allows the technical team to keep a constant watch over the performance of biogas upgrading units, ensuring that they operate within the desired parameters and that any deviations are promptly corrected.

The visit to Prodeval's facility provided valuable insights into the importance of remote monitoring and rapid response in the management of biogas upgrading operations. The advanced systems in place at Prodeval not only enhance the reliability and efficiency of their technologies but also set a high standard for the industry in terms of operational support and maintenance.

These insights are particularly relevant for any region or industry looking to implement or improve biogas upgrading technologies, including in Australia. The ability to remotely monitor and quickly respond to issues can significantly improve the overall performance and viability of renewable energy projects, making them more resilient and reliable in the long term.

5.1.9 Biomethane and Food Grade Bio-CO_2 Facility at Farming Operations - EON Aiterhofen

As part of the research project, the group visited a biomethane facility located at a farming operation on Amselfinger Str., 94330 Aiterhofen, Germany. This facility, operational since the summer of 2022, provided an look at how agricultural operations can effectively integrate biogas upgrading and CO_2 recovery technologies to enhance sustainability and generate additional revenue streams.

Figure 11. Outside view of Biomethane and Food Grade Bio-CO2 Facility at Farming Operations - EON Aiterhofen.

The highlight of the facility was the Cryotec CO_2 recovery unit, a state-of-the-art containerised system with a capacity of 1.7 tonnes per hour of food-grade CO_2. This system captures and purifies the CO2 produced during the biogas upgrading process, ensuring that the CO_2 meets the stringent standards required for food industry applications. The containerised design of the unit allows for flexibility and ease of installation, making it an ideal solution for similar farming operations looking to maximise resource recovery.

The facility features an older Pressure Swing Adsorption (PSA) unit for biogas upgrading. While PSA technology is well-established and reliable, its use in this facility highlights the potential for integrating newer technologies like CO_2 recovery with existing infrastructure. The biogas upgrading process at this site efficiently converts raw biogas into biomethane, which is then either injected into the local gas grid or utilised on-site.

The facility includes two large storage vessels, each with a capacity of 300 tonnes, dedicated to storing the recovered CO_2. This significant storage capacity ensures that the facility can maintain a steady supply of CO2 for commercial purposes. In addition to storage, the site is equipped with a truck filling station specifically designed for CO_2 trailers, facilitating the distribution of food-grade CO_2 to various industries. This infrastructure supports a seamless supply chain from production to end-use.

To ensure the quality of the CO_2 produced, the facility utilises a Carboscan analysis system. This system provides continuous monitoring and analysis of the CO_2, ensuring that it consistently meets the required purity standards for food-grade applications. The integration of such a robust quality control system is critical for maintaining the high standards necessary for the food industry.

The facility was constructed during 2021/22 and became operational in the summer of 2022. Despite being relatively new, the facility has already demonstrated its effectiveness in integrating biogas upgrading with CO_2 recovery, showcasing the potential for such technologies to enhance the sustainability of agricultural operations.

The visit to this biomethane facility underscored the significant opportunities for farming operations to leverage biogas and CO_2 recovery technologies. By integrating an older PSA unit with a modern Cryotec CO_2 recovery system, the facility exemplifies how existing biogas infrastructure can be upgraded to maximise resource efficiency and generate additional revenue streams. The substantial CO_2 storage and distribution capabilities, combined with the rigorous quality control provided by the Carboscan system, ensure that the CO2 produced is both high-quality and readily marketable.

The insights gained from this visit are particularly relevant for exploring similar opportunities in other agricultural regions, including Australia, where there is growing interest in sustainable farming practices and renewable energy production. The successful implementation of these technologies at this facility offers a model that could be adapted and replicated to enhance the environmental and economic sustainability of farming operations worldwide.

Figure 12. Biomethane and Food Grade Bio-CO2 Facility at Farming Operations - EON Aiterhofen.

5.1.10 Biomethane and Food-Grade BioCO_2 Recovery Facility at Food Waste Receival Facility

As part of the research project, we visited an advanced biomethane facility operated by ETW, located at Zur Reitbahn 1, 83620 Feldkirchen-Westerham, Germany. This facility, dedicated to processing food waste into renewable energy, represents a significant advancement in biogas technology and resource recovery.

The facility is designed to produce an impressive 1200 cubic metres per hour of biomethane, making it one of the more substantial operations of its kind. This high-output capacity is achieved through the efficient processing of food waste, which is converted into biogas via anaerobic digestion and subsequently upgraded to biomethane. The biomethane produced is intended for injection into the local gas grid, providing a renewable energy source to the surrounding community.

Figure 13. Biomethane and Food-Grade BioCO2 Recovery Facility at Food Waste Receival Facility in Feldkirchen-Westerham, Germany.

The highlight of this facility is its integrated food-grade CO_2 recovery system. This system captures CO_2 produced during the biogas upgrading process, purifies it to meet food-grade standards, and prepares it for commercial use in the food and beverage industry. The recovery and utilisation of CO_2 not only enhance the environmental sustainability of the facility by reducing greenhouse gas emissions but also create an additional revenue stream. The facility's CO_2 recovery system is expected to become operational in Q3 2024, marking a significant milestone in the facility's development. While the biomethane production is already in place, the full integration of the CO_2 recovery system is scheduled for completion and operational status by the third quarter of 2024. This phased approach allows for the gradual scaling of operations and the fine-tuning of processes to ensure optimal performance once the CO_2 recovery system comes online.

The visit to the ETW biomethane facility highlighted the potential for large-scale food waste processing operations to contribute significantly to renewable energy production and resource recovery. The facility's substantial biomethane output demonstrates the efficiency and scalability of biogas technology when applied to organic waste streams such as food waste. The upcoming integration of the food-grade CO_2 recovery facility is particularly noteworthy, as it represents a forward-thinking approach to maximising the value extracted from the biogas production process. By capturing and purifying CO_2 for use in the food and beverage industry, the facility not only reduces its environmental impact but also diversifies its revenue streams, making the operation more economically resilient.

The insights gained from this visit will be instrumental in understanding how similar technologies and processes can be applied in other regions, including Australia. The ETW facility serves as a model for how food waste can be effectively managed and transformed into valuable resources, contributing to both energy security and environmental sustainability. The upcoming CO_2 recovery system further exemplifies the potential for innovation in resource recovery, setting a new standard for integrated biogas facilities.

5.2 Interview with Travis McNeil

Q: How do you see the relevance and potential impact of emerging energy and waste management technologies on the Australian market, particularly in addressing the industry's sustainability and efficiency challenges?

Emerging energy and waste management technologies will be vital in the Australian market, particularly as we face the twin challenges of sustainability and efficiency. Technologies like biogas production, advanced recycling processes, and waste-to-energy systems offer significant potential to reduce greenhouse gas emissions, managing waste more effectively, and enhancing energy security. The integration of circular economy principles in waste management is not only helping to reduce waste but also creating valuable byproducts like biofuels and energy, thereby closing the loop in resource use.

Globally, countries are increasingly adopting these technologies, and Australia has the opportunity to position itself as a leader in this space by leveraging its abundant organic waste resources. As these technologies become more cost-effective and efficient, their adoption across various industries—from agriculture to manufacturing—can significantly contribute to a more sustainable and resilient energy system.

Q: What are your insights on the feasibility and adoption of advanced biomethane production and CO2 recovery technologies in Australia? How might these align with or challenge existing industry practices?

Biomethane production and CO_2 recovery technologies present a promising avenue for Australia to enhance its renewable energy portfolio and reduce its carbon footprint. The feasibility of these technologies is increasingly supported by advancements in biogas upgrading processes and carbon recovery techniques, which are becoming more efficient and cost-effective.

In Australia, the alignment of these technologies with existing industry practices is already evident in sectors like agriculture and waste management, where organic waste streams are abundant. For instance, the use of anaerobic digestion to produce biomethane from agricultural waste not only provides a renewable energy source but also offers farmers a sustainable way to manage waste. However, challenges remain, particularly in terms of infrastructure development and the need for regulatory frameworks that incentivise the adoption of these technologies.

The integration of CO_2 recovery with biomethane production could further align with Australia's carbon reduction goals, especially as industries look to offset emissions and improve their environmental footprint. The challenge lies in scaling these technologies and integrating them into existing supply chains, but with the right policy support and investment, these technologies could see widespread adoption.

Q: In your opinion, how well do large-scale wastewater-to-energy conversion technologies fit within the current trends in Australia? What factors could drive or hinder their adoption?

Large-scale wastewater-to-energy conversion technologies are increasingly relevant within Australia's current energy and sustainability trends. These technologies align well with the nation's goals of reducing waste, lowering carbon emissions and improving energy efficiency. The ability to convert wastewater into biogas or other forms of renewable energy not only provides a sustainable waste management solution but also contributes to energy security by diversifying the energy mix. The adoption of these technologies could be driven by several factors, including regulatory support for renewable energy, the rising cost of waste disposal, and the increasing focus on reducing the environmental impact of industrial processes. Additionally, the growing public and corporate focus on sustainability and the circular economy is likely to spur interest and investment in these technologies. However, there are also barriers to adoption, such as the initial capital costs, the need for specialised infrastructure and potential public resistance to new waste management practices. Addressing these challenges will require concerted efforts from industry, government, and the community to ensure that the benefits of wastewater-to-energy technologies are fully realised.

Q: Considering the shift towards repurposing infrastructure and integrating energy storage solutions like cogeneration and renewable energy management, how do you foresee these trends evolving in the Australian energy landscape?

The shift towards repurposing infrastructure and integrating energy storage solutions is set to play a crucial role in the evolution of Australia's energy landscape. As Australia moves towards a more decentralised and sustainable energy system, the repurposing of existing infrastructure—such as converting decommissioned coal plants into renewable energy hubs—will become increasingly common. This approach not only reduces the need for new construction but also maximises the use of existing assets. Cogeneration, or combined heat and power (CHP) systems, alongside energy storage solutions, will likely see significant growth as they offer enhanced efficiency and reliability for both industrial and commercial applications. These systems are particularly well-suited to Australia's diverse energy needs, from supporting remote communities to providing backup power for urban centres.

Q: How do you anticipate the development of hydrogen and combined heat and power (CHP) technologies in Australia, and what specific sectors or applications do you believe are most likely to benefit from these advancements?

Hydrogen and combined heat and power (CHP) technologies are poised to become key components of Australia's energy strategy, particularly as the country seeks to decarbonise its economy. Hydrogen, often referred to as the fuel of the future, has the potential to transform sectors like transportation, heavy industry and energy storage. Australia's vast renewable energy resources provide a strong foundation for producing green hydrogen, which can be used domestically or exported to meet growing global demand.

CHP technologies (now able to be fuelled by 100% Hydrogen) are particularly relevant for industries with high energy demands, such as manufacturing, agriculture, and food processing. These systems can significantly improve energy efficiency and reduce costs, making them an attractive option for businesses looking to enhance their sustainability credentials. The sectors most likely to benefit from these advancements include heavy industry, where hydrogen can replace fossil fuels in processes like steelmaking, and urban infrastructure, where CHP systems can provide reliable and efficient energy for residential and commercial buildings. The continued development and adoption of these technologies will be crucial for Australia to achieve its long-term energy and climate goals.

Q: How important is the role of government policy?

Government policy and regulation play a crucial role in driving the adoption of new energy and waste management technologies in Australia. Clear and supportive policies can create the right environment for innovation, investment and deployment of these technologies. To accelerate the transition, specific policies could include increased funding for research and development in emerging technologies, subsidies or tax incentives for businesses adopting sustainable practices, and stringent regulations on waste disposal that encourage the use of waste-to-energy and recycling technologies. Additionally, policies that promote the development of infrastructure, such as the expansion of the grid to support decentralised energy systems or the construction of bioenergy plants, would further support the adoption of these technologies. Collaborative efforts between government, industry, and the community are essential to achieving Australia's sustainability goals.

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5.3 IFAT Munich

Figure 14. Entrance to IFAT in Munich.

During the IFAT Trade Show, held from the 13th to the 19th of May 2024, I engaged with several leading suppliers who showcased cutting-edge technologies that are particularly relevant to the Australian red meat processing industry's goals for resource recovery and carbon neutrality. These visits provided critical insights into how these innovations could be applied to improve sustainability, efficiency, and carbon management within the sector.

Advanced Biogas Technologies (ABT) - Biogas Plants: ABT's expertise in designing and constructing biogas plants is particularly relevant to the red meat processing industry, where the treatment of organic waste is a significant concern. ABT's plants, known for their high load factors, are ideal for processing the organic fraction of waste, such as that produced by meat processing facilities. By converting waste into energy, these plants offer a sustainable solution that reduces waste disposal costs and contributes to carbon neutrality goals through renewable energy production.

Aquamont's Molecular Disruption Technology offers a cutting-edge solution for the Australian red meat processing industry by providing superior water treatment through a physicochemical process. This technology enhances contaminant removal, re duces chemical usage, and operates with high energy efficiency, making it an ideal choice for processors focused on resource recovery and carbon neutrality. With its ability to produce lower sludge volumes and adapt to various wastewater types, Aquamont's technology aligns perfectly with the industry's sustainability goals, offering a streamlined, cost-effective approach to meeting stringent environmental regulations.

Bright - Carbon Capture: Bright Renewables presented their modular carbon capture systems, which are particularly relevant for the Australian red meat processing industry's efforts to reduce greenhouse gas emissions. These systems capture CO_2 from combustion processes and convert it into liquid or gaseous CO_2, which can be utilised or sold. By integrating such technology, meat processors could significantly reduce their carbon footprint, aligning with national and industry-specific carbon neutrality targets.

Clean Water Technology - GEM System: Clean Water Technology's GEM system, which uses hydro-cyclone technology to enhance wastewater treatment, is especially pertinent for meat processors dealing with large volumes of effluent. The system's ability to remove more contaminants and produce drier sludge can significantly improve the efficiency of wastewater management processes in meat processing facilities. By adopting such technologies, processors can better manage their water resources, reduce waste, and contribute to overall sustainability goals.

CNP CYCLES GmbH: CNP Cycles specialises in providing innovative technologies for nutrient recovery and energy optimisation in wastewater treatment plants. Particularly in Germany, where new regulations require the recovery of phosphorus—a critical and finite nutrient—from sewage sludge, CNV Cycles leads the way in this rapidly expanding field. The company's technologies, such as LysoPhos® P-Recovery and AirPrex® Sludge Optimisation, are engineered to meet these regulatory requirements and support sustainable practices in wastewater management, establishing CNV Cycles as a key player in the global drive to optimise valuable resources.

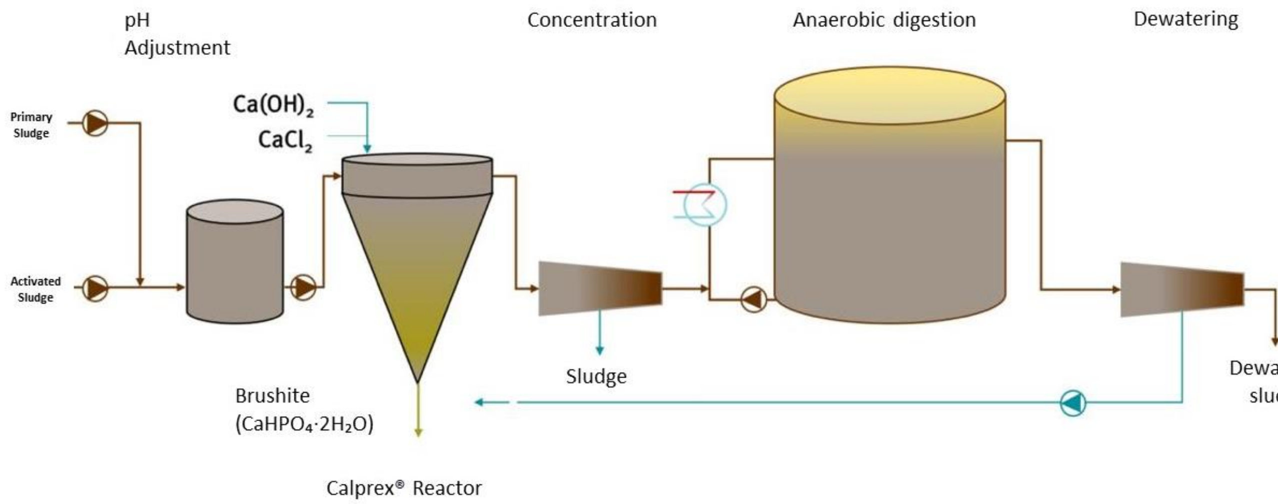

Figure 15. Lysophos® – P-Recovery with thermal hydrolysis developed by CNP CYCLES GmbH.

Lysophos® – P-Recovery with thermal hydrolysis: Thermal hydrolysis or thermal chemical hydrolysis before anaerobic digestion enables the polyphosphate bound by Bio-P (EBPR) to be dissolved back as far as possible. The hydrolysed sludge is dewatered so that most of the redissolved phosphate is in the centrate. With the addition of ammonium in the form of e.g. centrate water from the dewatering after digestion, the precipitation of the ortho-phosphate as struvite takes place.

After separation of the struvite, the phosphate-depleted centrate is partially or completely remixed with the pre-dewatered sludge and fed to the digestion. The hydraulic load on the digester can be reduced by increasing the TR in the influent if the sludge is only partially remixed with centrate.

Dorset - Digestate pelleting systems: Dorset produces complete pelleting and packaging factories for quantities up to 4000 kg/h using Kahl presses or multiple small presses. Dorset can deliver the full-package, including the required engineering work, service afterwards, storage of the end products etc.

Figure 16. Overview of IFAT Exhibition Hall.

HeGeo Biotec - FerroSorp S Hydrogen Sulfide Filter Media: HeGeo Biotec's FerroSorp S technology, which removes hydrogen sulphide from biogas, is highly relevant to biogas operations within the red meat processing industry. Hydrogen sulphide can be a significant contaminant in biogas, and efficient desulphurisation is crucial for maintaining high-quality biogas production. This technology ensures that biogas generated from organic waste is cleaner and more efficient, supporting the industry's goals for resource recovery and renewable energy production.

Prodeval - V'COOL CO_2 Liquefaction: Prodeval introduced their V'COOL CO2 liquefaction technology, which is highly pertinent to the Australian red meat processing industry's carbon neutrality targets. Following biogas upgrading to biomethane, this system captures and liquefies the CO2, which can then be marketed for use in various industries. Additionally, any residual methane is recovered and returned to the biogas plant, further enhancing resource efficiency. The ability to turn waste CO2 into a marketable product aligns with the industry's drive to minimise emissions and generate additional revenue streams, supporting both environmental and economic sustainability.

Pyrodry - Energy Self-Sufficient Drying and Pyrolysis System: Pyrodry's innovative system for converting organic sludge into BioChar through drying and pyrolysis is particularly beneficial for red meat processors. This technology offers a sustainable way to manage organic waste, turning it into a valuable by-product that can be easily transported and utilised. The system's energy self-sufficiency and ability to reduce waste volumes align with the industry's objectives to enhance resource efficiency and reduce carbon emissions.

Rielli - Water Treatment Plants: Rielli's water treatment technologies, particularly their MBBR and MBR systems, are highly applicable to the red meat processing industry. These systems provide advanced biological treatment of wastewater, helping processors meet environmental standards and reduce water usage. Incorporating Rielli's technologies can improve the efficiency of wastewater management in meat processing plants, supporting resource recovery and reducing the industry's environmental footprint.

Simpec - Wastewater Treatment Plants: Simpec's wastewater treatment solutions are directly applicable to the red meat processing industry, which requires robust systems to manage industrial effluents. Simpec's technologies, including chemical/physical purification and biological treatment systems, offer scalable solutions that can help processors meet stringent environmental regulations while improving water reuse and reducing operational costs. Effective wastewater management is essential for maintaining environmental compliance and enhancing sustainability in meat processing operations.

Teknofanghi - Monobelt Belt Filter Press: Teknofanghi's Monobelt belt filter press, which combines thickening and sludge pressing, is a valuable addition to the toolkit of red meat processors. This technology allows for effective dewatering of sludge, producing higher dry solids content and reducing the volume of waste that needs to be disposed of. By improving sludge management processes, this technology can help meat processors reduce waste disposal costs and improve sustainability outcomes.

UGN Systems - Gas Desulphurisation: UGN Systems' gas desulphurisation technologies are crucial for maintaining the quality of biogas produced in meat processing plants. Their systems, including the BEKOM H and UgnCleanPellets S 3.5 filtering material, offer reliable and efficient removal of hydrogen sulphide, ensuring that biogas is clean and suitable for energy production. By adopting these systems, red meat processors can enhance the efficiency of their biogas operations and reduce sulphur emissions, furthering their sustainability efforts.

Watropur - WATROMAT Low Temperature Sludge Dryer: Watropur's WATROMAT low-temperature drying systems offer an effective solution for drying sludge generated by wastewater treatment plants in meat processing operations. The closed-loop system ensures no emissions or odours are released, making it environmentally friendly. Implementing this technology could help Australian red meat processors manage sludge more efficiently, reduce disposal costs, and minimise environmental impact, contributing to the sector's carbon neutrality objectives.

Witkowitz - Wastewater Treatment and Biogas Plants: Witkowitz's offerings in wastewater treatment and biogas plant construction are of particular interest to Australian red meat processors. Their wastewater treatment technologies are designed to handle effluents from food and agricultural industries, making them well-suited to the specific needs of meat processors. Additionally, Witkowitz's biogas plants, which convert biogas into biomethane, provide a dual benefit of waste management and renewable energy generation. Implementing these technologies could significantly advance the industry's efforts in resource recovery and carbon reduction.

These visits highlighted the relevance of these technologies to the Australian red meat processing industry, particularly in advancing resource recovery and achieving carbon neutrality. The insights gained from these interactions will be crucial in guiding the industry towards adopting innovative solutions that enhance sustainability, improve operational efficiency, and support the sector's long-term environmental goals. Table 1 summarises all the visited suppliers and their technologies.

Table 1. Summary of suppliers visited at IFAT in Munich.

Supplier	Website	Technology	Brief Description
Advanced Biogas Technologies (ABT)	www.abtbiogas.de	Biogas Plants	Design and construction of biogas plants. ABT is a German company focused on the treatment of the organic fraction of municipal waste and poultry waste. ABT has been involved in the construction of biogas plants that have been awarded for their high load factor.
Bright	www.bright-renewables.com	Carbon Capture	CO_2 from combustion flue as is captured and converted into liquid or gaseous CO_2. This allows thermal energy plants to reduce CO_2 emissions. Technology is characterised by a modular approach. The units are available in the range of 200-8000 kg/hour CO_2, and can deliver the CO_2 in gaseous or, when combined with a CO_2 liquefaction system, liquid form.
Clean Water Technology	www.cwt-global.com	Wastewater Treatment – Gas Energy Mixing (GEM) System	The GEM system uses unique hydro-cyclone technology in the Liquid, Solid, Gas Mixing Heads (LGSM). In these heads air is dissolved into 100% of the wastewater stream while creating a vortex. The random flocculation and flotation process of a DAF system becomes a managed process in the GEM system, resulting in the removal of more contaminants and drier sludge.
CNP Cycles	https://cnp-cycles.de	Nutrient recovery	Innovative Technologies for nutrient recovery and energy optimisation of wastewater and water treatment plants.

			Energy efficiency to reduce costs on wastewater treatment plants. Nutrient recovery for sustainability in operation. Clean water for health, hygiene and as the core of growth and development. Comprehensive services and operational support to optimise plant efficiency.
Dorset	www.dorset.nu	Digestate pelleting systems	Dorset produces complete pelleting and packaging factories for quantities up to 4000 kg/h using Kahl presses or multiple small presses. Dorset can deliver the full-package, including the required engineering work, service afterwards, storage of the end products etc.
HeGeo Biotec	www.hego-biotec.com	FerroSorp S - Pelletised Hydrogen sulphides filter media	FerroSorp S is a pelletised media based on iron hydroxide for external desulphurisation in agricultural biogas plants. Gas containing H2S is passed through a filter vessel filled with FerroSorp S pellets. H2S and iron hydroxide react for form solid iron sulphide. Second- either simultaneously or in parallel, oxygen convers the pellets back into iron hydroxide. Elemental sulphur is formed and accumulates within the pores of the media pellets.
Prodeval	www. prodeval.com	V'COOL - CO2 Liquefaction.	Following the upgrading of biogas into biomethane, the stream released into the atmosphere contains high amounts of CO_2. V'COOL unit liquefies the CO_2, while recovering residual methane which can be returned to the biogas plant. The liquefied CO_2 can be marketed to various industries.
Pyrodry	www.aquaagain.dk	Energy self-sufficient drying and pyrolysis in one system	Converts organic sludge into valuable BioChar using a drying system and pyrolysis oven. The sludge is dried and pulverised in the drying oven before being formed into pellets and converted into BioChar in the oven. The use of pellets creates a uniform, easily handled substance that is easy to transport. The system utilises the energy and heating value of the BioChar. The hot gas generated in the pyrolysis oven is directed into the drying oven, whilst being cooled by fresh air, resulting in low energy consumption.
Rielli	www.rielli.com	Water Treatment Plants – MBBR Plants	Moving Bed Biofilm Reactor (MBBR) is a simple structure system installed using thousands of polyethylene biofilm bearing chips added into a treatment tank without requirement of a further plant installation or construction. Chips have an active surface area of 4850 m^2/m^3.
Simpec	www.simpec.it	Wastewater Treatment Plants	Simpec designs and builds wastewater treatment plants for industrial discharges of any size. Simpec builds two types of wastewater treatment plants: chemical/physical purification plants (continuous and discontinuous batch) and biological purification plants.
Teknofanghi	www.teknofanghi.com	Monobelt - Belt Filter Press	Combination of a thickener and belt filter press. The machine is composed of two units, the pre-thickener, that performs initial solid/liquid separation, and the sludge press. It is possible to reach dry solids content between 18 – 30%.
Teknofanghi	www.teknofanghi.com	Scrudrain – Dynamic thickener with	Scrudrain thickeners uses an Archimedean screw instead of a conventional drum filter. The Archimedean screw allows an adjustment of the concentration of the thickened sludge,

		internal Archimedean screw.	creating a continuous mix that aids the drainage of the water and minimises the use of polyelectrolytes.
UGN Systems	www.ugn-umwelttechnik.de	UGN Gas desulphurisation systems for biogas plants.	Systems are made for external bio-chemical final desulphurisation which has proven a reliable process for reducing high hydrogen sulphide loads to less than 5 ppm. The desulphurisation system is set up outside the digester to facilitate regulating and maintenance, without interfering with processes running inside the digester. The biogas requires no drying before being fed into the system.
UGN Systems	www.ugn-umwelttechnik.de	BEKOM H system	Compact gas desulphurisation system comprising a reactor, a meter cabinet, and a switching cabinet. It selectively removes hydrogen sulphide from biogenic fuel gases. The moist and hot raw gas is directed through the UgnCleanPellets S 3.5 filtering material, where the sulphur is removed immediately. System can be used for both coarse and fine desulphurisation. The gas is conditioned automatically so that the system is always running at its optimal point.
UGN Systems	www.ugn-umwelttechnik.de	UGN Clean Pellets S 3.5 Filtering Material	Pellets made for separation of compounds with high and very high sulphur content.
Watropur	www.watropur.com	Sludge dryer – WATROMAT low temperature batch and continuous drying systems.	WATROMAT low temperature drying system is designed to dry all sludge from industrial or municipal waste water treatment plants with a dried solids content greater than 20% D.S. Dry air generators extract the moisture from the sludge and the dry air is reintroduced back to the sludge in a continuous cycle. Since the drying process is carried out in a closed system at low temperatures, there is no emissions to the surrounding atmosphere and no smell.
Witkowitz	www.witkowitz-envi.cz	Wastewater Treatment Plants	Witkowitz, design and construct wastewater treatment plants for treatment of wastewater from municipalities, food and agricultural industries.
Witkowitz	www.witkowitz-envi.cz	Biogas Plants	Witkowitz engineer, produce, and service biogas plants, and offer optimal technology solutions for specific input materials. The plants provide a technology for the conversion of thermal energy into electrical energy and upgrading of biogas to biomethane.

5.4 A Cultural Note: The Otto A Compression Engine

During the stay to Munich, I had the opportunity to explore the Deutsches Museum, where I was captivated by the Otto A compression engine, among many other fascinating technologies on display. Seeing this iconic piece of engineering history in person brought to life the incredible impact that Nikolaus Otto's innovation had on the energy industry and modern technology. The Otto A compression engine (Figure 17) represents one of the most significant advancements in mechanical engineering of the 19th century. Nikolaus Otto's development of the four-stroke engine cycle—often referred to as the "Otto cycle"—was a transformative moment that laid the groundwork for the internal combustion engines that have powered the world's transportation and machinery for over a century.

Figure 17. The Otto A engine, preserved in the Deutsches Museum.

The Otto A engine operates on the four-stroke cycle, which includes the intake, compression, power, and exhaust strokes. This engine's design, characterised by its simplicity and robustness, was revolutionary for its time. The successful implementation of compressing the fuel-air mixture before ignition significantly improved the engine's efficiency and power output, setting it apart from earlier designs. The Otto A engine marked a major turning point in the energy industry. Prior to its invention, steam engines, which relied on external combustion, were the dominant technology. The internal combustion engine, exemplified by the Otto A, offered a more compact, efficient, and versatile solution, which led to its widespread adoption in automobiles, ships, and industrial machinery.

Reflecting on the evolution of the energy industry, from the era of the Otto A engine to the present day, it is clear that continuous innovation has been a constant driving force. The principles established by the Otto engine have been refined and evolved, leading to the development of modern internal combustion engines that continue to power much of today's world. However, this technology also laid the groundwork for the next wave of energy innovations.

In recent years, the energy industry has been transitioning towards sustainability, driven by the urgent need to reduce greenhouse gas emissions and combat climate change. This shift is evident in the growing adoption of renewable energy sources and the development of new technologies such as electric vehicles and hydrogen fuel cells. The advancements in biogas and biomethane production, as seen in the modern facilities I visited during this project, represent a continuation of this trend, focusing on harnessing renewable resources to produce clean energy.

6 Discussion

The site visits conducted as part of this project provided critical insights into the advanced bioresources recovery technologies currently utilised across various sectors in Germany. These visits, which included biogas plants, biomethane facilities, cogeneration plants, and wastewater treatment systems, allowed for a thorough comparative analysis between European and Australian approaches to resource recovery, with a focus on their potential applicability within the Australian red meat processing industry. This discussion synthesises the findings from the site visits, assesses the feasibility of adopting these technologies, and presents actionable recommendations tailored to the Australian market.

The technologies observed at facilities such as the ETW Factory, Prodeval Facility, and various biomethane plants highlighted the maturity and sophistication of bioresources recovery in Germany. These technologies are not only highly effective in converting organic waste into valuable products like biomethane and bioCO2 but also play a significant role in improving energy efficiency and supporting carbon neutrality goals. The outcomes from these visits suggest strong potential for adapting and implementing similar technologies within the Australian red meat processing industry, where the need for sustainable waste management and energy solutions is becoming increasingly urgent.

A comparative analysis between Australian and EU bioresources recovery technologies revealed several key differences. In the EU, there is a strong emphasis on integrating advanced biogas upgrading and CO2 recovery systems into existing operations. For example, at the ETW Factory and Prodeval Facility, systems that capture and purify CO2 for food-grade applications provide both environmental and economic benefits. Facilities like the Biomethane Facility at the Food Waste Receival Facility illustrate how integrating bioCO2 recovery into the production process can turn waste products into valuable resources, creating new revenue streams.

In contrast, Australian facilities tend to rely more heavily on traditional waste management practices, with less focus on advanced resource recovery technologies. Adopting EU technologies in Australia could bridge this gap, enabling the red meat processing industry to achieve higher levels of resource efficiency and progress towards carbon neutrality. For instance, the technologies observed at the Biolesker Bioladen Biogas Plant could be adapted to use organic waste from meat processing, transforming it into energy and valuable by-products.

The feasibility of adopting these technologies in Australia was assessed through both technical and economic lenses. Technologies such as the CO2 recovery systems at the Biomethane and Food-Grade BioCO2 Recovery Facility at EON Aiterhofen, which produce high-purity CO2, could be particularly valuable for the Australian food and beverage industry. However, the high capital costs and energy requirements associated with these systems necessitate careful financial planning and possibly phased implementation to ensure economic viability.

The business models observed during the site visits, particularly at the Prodeval Facility and the Peaking Plant in Duisburg, Germany, emphasise the integration of resource recovery into the broader operational and financial strategy. The sale of biomethane and bioCO2 provides a steady revenue stream that supports the sustainability of these operations. In Australia, similar models could be explored, with partnerships between technology providers and red meat processors helping to share the financial burden and reduce risk.

For example, the modular design of the 2G Factory’s cogeneration units offers a scalable approach that could be gradually implemented in Australian facilities, aligning with industry operational and budgetary constraints. The integration of these technologies into existing plants, as observed at the Peaking Plant Duisburg, also highlights the potential for retrofitting Australian facilities to improve energy efficiency and reduce emissions.

Interviews with stakeholders in the Australian red meat processing industry revealed cautious optimism about adopting advanced bioresources recovery technologies. While there is strong interest in improving sustainability, stakeholders expressed concerns about the upfront costs, potential disruptions during implementation, and the need for ongoing technical support. These concerns underscore the importance of providing clear information about the long-term benefits of these technologies and ensuring that adequate training and support are available.

The feedback also highlighted the need for a collaborative approach, where industry players work together to share knowledge and resources. This could be facilitated through industry associations or government-backed initiatives that provide financial incentives and technical assistance.

Actionable Recommendations for the Australian Red Meat Processing Industry

Based on the findings from the site visits and stakeholder feedback, several actionable recommendations have been developed for the Australian red meat processing industry:

1. Adopt Biogas Upgrading and CO2 Recovery Technologies: Focus on integrating biogas upgrading systems, such as those observed at the ETW Factory and the Biomethane Facility at the Food Waste Receival Facility, to convert organic waste into valuable products. CO2 recovery systems should be prioritised for their dual benefits of emissions reduction and revenue generation.

2. Implement Modular and Scalable Solutions: Consider the phased adoption of modular technologies, such as those from the 2G Factory, to gradually enhance resource recovery capabilities without overwhelming operational budgets.

3. Foster Public-Private Partnerships: Encourage partnerships between technology providers, government bodies, and industry stakeholders to share the costs and risks associated with adopting advanced technologies. These partnerships could also help secure funding and subsidies to support implementation.

4. Invest in Training and Support: Develop comprehensive training programmes to ensure that plant operators are equipped to manage and maintain new technologies effectively. This will help minimise operational disruptions and maximise the benefits of the technologies.

5. Conduct Pilot Projects: Launch pilot projects in collaboration with technology providers to test the feasibility of bioresources recovery technologies in the Australian context. These projects can serve as models for broader implementation across the industry.

6. Promote Industry Collaboration: Establish platforms for industry-wide collaboration to share best practices, case studies, and lessons learned. This can accelerate the adoption of bioresources recovery technologies and ensure that the industry moves collectively towards greater sustainability.

The insights gained from the site visits and research activities underscore the significant potential for the Australian red meat processing industry to enhance its sustainability practices by adopting advanced bioresources recovery technologies. The EU’s experience, particularly in biogas upgrading and CO2 recovery, offers valuable lessons that can be adapted to the Australian context. By following the actionable recommendations outlined above, the industry can take proactive steps towards a more sustainable and efficient future.

7 Conclusions & Recommendations

This study has provided an assessment of the potential for EU bioresources recovery technologies to enhance the sustainability and efficiency of the Australian red meat processing industry. The conclusions drawn highlight key insights, opportunities, and strategic recommendations for industry stakeholders.

The evaluation of bioresources recovery technologies, showcased at the IFAT trade fair and through visits to Evo Environmental Technologies, revealed significant advancements in waste-to-energy conversion, nutrient recovery, and wastewater treatment. These technologies have high applicability to the Australian red meat processing industry, particularly in addressing environmental challenges and improving resource efficiency. However, successful adaptation to the Australian context requires careful consideration of local conditions, including regulatory frameworks, operational scales, and market demands.

Case studies from the EU demonstrated the substantial operational, environmental, and economic benefits achieved through the adoption of advanced technologies. These examples underscore the importance of tailored solutions, the critical role of government incentives and regulations in driving adoption, and the economic viability gained through resource recovery and circular economy practices. The comparative analysis between Australian and EU practices identified several areas for improvement in Australia, including underutilisation of waste streams, lower levels of energy recovery, and limited integration of advanced wastewater treatment technologies. These gaps present clear opportunities for technology transfer, adaptation, and innovation within the Australian context.

The exploration of renewable resource opportunities, such as biogas, biomethane, and food-grade bioCO2 production, highlighted their technical feasibility and potential benefits for the Australian red meat processing industry. Adoption of these technologies could lead to significant reductions in greenhouse gas emissions, lower operational costs, and the creation of new revenue streams from recovered resources. The recovery of food-grade bioCO2, in particular, presents a promising opportunity both in terms of sustainability and economic returns. However, successful implementation will require addressing challenges such as infrastructure development, market readiness, and alignment with existing operations.

Insights from interviews with Australian food processors revealed a strong interest in sustainability and resource efficiency, coupled with concerns about initial investment costs, technology integration, and the need for technical expertise. These insights highlight the importance of developing supportive frameworks, including financial incentives, knowledge sharing, and technical assistance, to facilitate technology adoption.

The analysis of business models and technology adaptations identified several strategies to support the adoption of bioresources recovery technologies in Australia. Collaborative approaches, such as industry partnerships, public-private collaborations, and the development of shared facilities, were identified as key enablers. Additionally, adapting EU technologies to meet the specific needs of Australian processors, including scaling technologies to match production volumes and modifying processes to comply with local regulations, will be essential for successful implementation.

Based on these findings, actionable recommendations for the Australian red meat processing sector include:

- Prioritising the adoption of waste-to-energy technologies to improve sustainability and reduce operational costs.

- Developing industry-specific guidelines and best practices for integrating bioresources recovery technologies.

- Establishing financial incentives and support mechanisms to lower barriers to technology adoption.

- Promoting industry collaboration and knowledge sharing to accelerate the diffusion of innovative technologies.

Furthermore, enhancing awareness and understanding within the Australian red meat processing industry is crucial for driving the adoption of bioresources recovery technologies. This can be achieved through targeted industry engagement initiatives, training programmes, and the dissemination of case studies and success stories. By increasing industry knowledge, stakeholders will be better equipped to make informed decisions that enhance sustainability, efficiency, and profitability.

The integration of EU bioresources recovery technologies present a significant opportunity for the Australian red meat processing industry to enhance its environmental performance and economic viability. By leveraging the insights and recommendations from this study, industry stakeholders can take proactive steps towards a more sustainable and efficient future.

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8 Bibliography

Not applicable.

9 Appendices

Not applicable.