



Beyond Efficiency

Circular economy opportunities for Australian dairy

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New South Wales

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Executive Summary

Over the past twenty-five years, the Australian dairy industry has responded to deregulation, drought, market volatility and rising production costs through continual improvements in efficiency. These gains have produced one of the world's most productive dairy industries. Yet many of the structural challenges now facing Australian dairy, including rising input costs, labour constraints, climate variability, and increasing expectations around environmental stewardship, cannot be addressed through efficiency alone. Australia's next productivity gains will depend on creating greater value from the resources already committed to production.

This report argues that circularity should not be viewed primarily as a waste management or sustainability initiative, but as a framework for improving resource productivity. Through the study of leading dairy businesses and agricultural organisations across Europe, the Middle East, North and South America, and Asia, the research found that the most successful businesses consistently redesign production systems to increase the productive value generated from natural resources, biological capital and human capability. Viewed this way, circularity becomes a commercial strategy that strengthens profitability, resilience, and long-term competitiveness.

Three interconnected resource loops provide the framework for understanding circularity in dairy. The natural resource loop focuses on increasing the productivity of land, water, nutrients, and energy. The biological loop increases the lifetime value generated from livestock through genetics, nutrition, health, and production system design. The human loop improves labour productivity and management capacity by redesigning work, integrating technology, and enabling people to contribute higher-value tasks within the business.

The research also found that technology is rarely the primary constraint to circularity. Many of the technologies and management approaches required already exist. Adoption depends on the environment in which investment decisions are made. Government policy, industry leadership, finance, supply-chain incentives, and practical decision support all influence whether businesses invest in long-term production system redesign. Circularity becomes mainstream when these institutions consistently reward productivity rather than individual technologies.

To accelerate adoption across the Australian dairy industry, this report recommends for the:

1. **Development of national guidelines for circular dairy production system design** to provide Australian farmers with practical decision-support, investment guidance and an evidence base for production system redesign.
2. **Creation of a policy environment that encourages long-term investment and protects productive agricultural capacity** by reducing regulatory complexity and providing stable policy settings that strengthen investment confidence.
3. **Alignment of agricultural finance with long-term value creation** by recognising investments that improve resource productivity, business resilience and long-term commercial performance.

4. **Reward for value creation across the dairy supply chain** by developing commercial mechanisms that recognise and share the value created through circular production systems.
5. **Embed circular production system design within Australia's future dairy strategy** through industry strategy, research, education, and extension.

This report defines circularity as the deliberate redesign of dairy production systems to improve the productivity of the resources already committed to production. Circularity is presented as a commercial framework for improving the productivity of natural resources, biological capital, and human capability.

Keywords: dairy, circular economy, resource productivity, production systems, Australian agriculture

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Foreword

Growing up in an intergenerational dairying family in New South Wales, my life has been signposted by the challenges and disruptions that have defined Australian dairy since deregulation. As our industry began to consolidate and shrink, my parents saw opportunity and moved our herd of registered Holsteins from traditional dairy country in the Hunter Valley to the state's Central West in 2004. What was traditionally a mixed farming and broadacre cropping region provided the secure water and access to fodder markets that enabled sustainable growth and security to continue farm into future generations.

"Cows come first" and *"If you take care of the little things, the big things take care of themselves"* were the principles that all decisions were based on. Drought and market pressures precipitated three-times-a-day milking in 2007, and as the supermarkets \$1-a-litre milk war devastated farmgate milk prices my family doubled down on dairy. In October of 2013 the first bottle of our own milk left our new on-farm factory under The Little Big Dairy Company brand.

Growing up in this environment meant I understood there was always a better way of doing things, and that all challenges presented an equal opportunity. And in 2022 after more than a decade studying and working in economics and infrastructure advisory in Sydney and Melbourne, I returned home with a new set of skills and experiences that made it difficult to see our farm as anything other than an integrated production system.

Applying for a Nuffield Scholarship in 2024, I hoped to get off farm and find the next enablers of efficiency and sustainability for our vertically integrated business. I saw Nuffield as an opportunity to focus on the 1 per cent opportunities that would have the greatest impact.

What I gained from Nuffield is so much more than the shopping list of infrastructure and technology I thought I would return with. It has given me a new understanding of how value is created, and recast circularity as a structural framework more so than sustainability byword.

Table 1. Travel itinerary

Travel date	Location	
September 01 – 06, 2024	Launceston TAS, Australia	Nuffield Australia National Conference and Farm Tours
February 10-11, 2025	Homebush NSW, Australia	Royal Agricultural Society
March 03 – 07, 2025	Canberra ACT, Australia	Nuffield Australia Australian Focus Program
March 08 – 16, 2025	Auckland, New Zealand	Nuffield Contemporary Scholars Conference
March 17 – 22, 2025	North Island, New Zealand	Post CSC individual farm tour
June 21 – 26, 2025	Qatar	
June 27 – July 02, 2025	Normandy France	Nuffield United Kingdom Dairy Tour France
July 03 – 25, 2025	South West and North West England and Scotland United Kingdom	
July 26 – August 07, 2025	The Netherlands	
September 04 – 05	New South Wales, Australia	Pre GFP tour for Dutch and Brazilian dairy farmers
September 06 – October 11	Adelaide SA, Australia Singapore The Philippines Denmark California, United States of America Chile	Global Focus Program
October 12 – 23, 2025	Chile	International Dairy Federation World Dairy Summit
April 28, 2026	Melbourne VIC Australia	Dairy Australia Australian Dairy Sustainability Framework Working Group Workshop
May 22 – 26, 2026	Devon, England United Kingdom	
August 26 - 27, 2026	Dubbo NSW Australia	National Bush Summit

Acknowledgments

The Nuffield experience has been the most rewarding of my life. I am humbled and privileged to have been afforded such an opportunity. Thank you to Nuffield Australia and my sponsors the RAS Foundation, Royal Agricultural Society of NSW, and NSW Nuffield Alumni. Support from the RAS has made the scholarship particularly meaningful, given the Sydney Royal Easter Show has been part of my family's life for generations.

I am indebted to innumerable Nuffield alumni for their hospitality and time. Whether over a tea or a beer, the conversations and insights were as valuable as the farms, businesses, and universities I visited.

Thank you to those outside of Nuffield who responded to an email or whatsapp from a random Australian dairy farmer requesting a visit or call. My experience was enriched by your generosity, unique perspectives, and willingness to openly share your work.

Special thanks to Jodie Redcliffe, Tessa Dimond, and Carol Miller for the enormous amount of work you do in the background. Your passion for the Nuffield experience has created a year like no other. Thank you to the GFP country hosts who gave up their time and drew on their networks to create unforgettable experiences for our group.

One of the greatest experiences of the scholarship was travelling with my dad, Steve, to Qatar and onto France as part of the Nuffield United Kingdom Dairy Tour in Normandy. The community the UK alumni is exceptional, thank you to Mike Brady (International Chair) and Tom Rawson (UK Chair).

Most importantly my Nuffield would not have been possible without the support of my family. Thank you Mum for letting Dad visit Paris for the first time without you. Emma, Xavier and Wilfred for your excitement, encouragement, and all the slack you picked up for me while I was travelling. This report is the culmination of two years of work and travel, it is yours as much it is my own, thank you.

Artificial intelligence tools were used in the preparation of this report, including for the design of figures, appendix tables, support in synthesising, and organising ideas in the writing process. All research, analysis, interpretations and conclusions are the author's own.

Abbreviations

ABARES	Australian Bureau of Agricultural and Resource Economics and Sciences
ABS	Australian Bureau of Statistics
ACCU	Australian Carbon Credit Unit
AD	anaerobic digestion
AI	artificial intelligence
ARENA	Australian Renewable Energy Agency
CE	circular economy
CEFC	Clean Energy Finance Corporation
CO ₂ -e	carbon dioxide equivalent
DA	Dairy Australia
DAFF	Department of Agriculture, Fisheries and Forestry
DAP	diammonium phosphate
DCCEEW	Department of Climate Change, Energy, the Environment and Water
N	nitrogen
NPK	nitrogen, phosphorous and potassium
QEERI	Qatar Environment and Energy Research Institute, Hamad Bin Khalifa University
TMR	total mixed ration

Objectives

The objectives of this report are to:

- Establish a practical framework for understanding circularity in Australian dairy through the lens of resource productivity.
- Examine international examples of production system redesign that improve the productivity of natural resources, biological capital and human capability.
- Recommend the policy, industry and commercial changes required to position circularity as Australia's next productivity reform.

Introduction

Few Australian agricultural industries have experienced greater structural change than dairy. In just twenty-five years, deregulation, drought, supermarket price competition, and rising production costs have transformed one of Australia's most protected agricultural industries into one of its most exposed (Australian Competition and Consumer Commission [ACCC], 2001). Sold on a free market dream of deregulation in 2000 (Sheng et al., 2020), the industry has achieved substantial gains in productivity through structural consolidation, yet it has also become more vulnerable to market volatility, climate shocks, and rising input costs (Australian Bureau of Agricultural and Resource Economics and Sciences [ABARES], 2020; Australian Dairy Farmers, 2022). An almost halving of the real farmgate value of milk precipitated a rapid exodus from the industry and contributed to a devaluing of dairy in the eyes of Australian consumers (Somerville, 2020; Edwards, 2003).

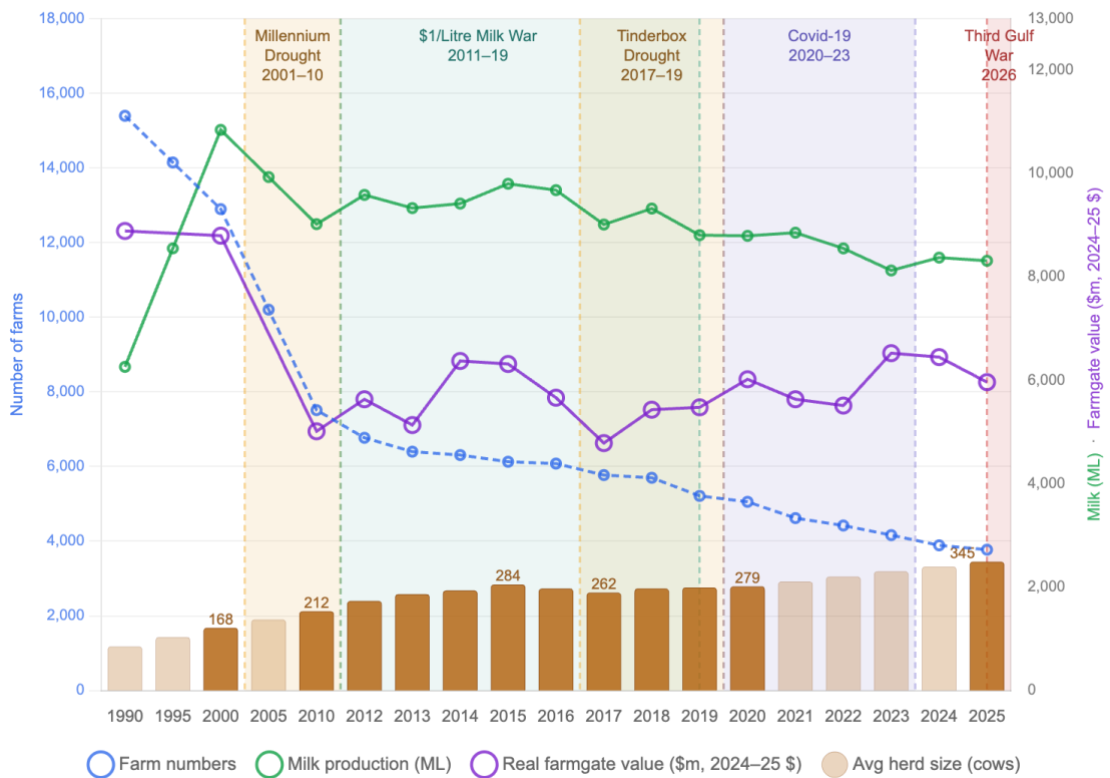


Figure 1. Australian dairy industry trends, 1990–2025. Farm numbers, milk production, real farmgate value (2024–25 dollars) and average herd size. (Source: Arthur). (Sources: Dairy Australia [DA], 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2025; Department of Agriculture, Fisheries and Forestry, 2023; Australian Bureau of Statistics, 2025.)

The decade following deregulation was mired in the Millennium Drought and turbulence in global markets, conditions that left the industry exposed to the \$1/Litre Milk War, which from 2011 accelerated the decline in both farm numbers and the national milk pool. The collapse of Murray Goulburn in 2016, and the subsequent

retrospective milk price clawback, devastated many Victoria dairy businesses and severed trust between farmers, processors, industry, and government. The crisis ultimately led to the development of the Dairy Industry Code of Conduct, introducing greater transparency and accountability into milk supply agreements (Competition and Consumer (Industry Codes—Dairy) Regulations 2019 (Cth)).

Farmgate milk prices recovered through the mid-2010s before declining again as south-eastern Australia returned to drought. Global uncertainty and supply chain disruption in the early 2020s brought an uneasy period of stabilisation. Farmgate prices recovered through 2023–24, but the industry's fundamental challenges remain.

To have remained dairying through this period demanded a relentless pursuit of on-farm efficiency. Decades of improvement in genetics, nutrition, mechanisation, and management have driven substantial productivity gains, allowing Australian dairy to remain globally competitive without the production subsidies available to many competing nations (ABARES, 2024).

This efficiency has not resolved the structural constraints limiting Australian's future competitiveness. The industry has maintained competitiveness largely through linear consolidation: fewer farms, larger herds, more milk per cow, greater output per labour unit, more value from every hectare, and in many businesses, greater debt. (ABARES, 2024; Beca, 2021).

Productivity gains have not removed the industry's exposure to rising input costs, labour constraints, and growing expectations around environmental stewardship and animal welfare (DA, 2024; von Keyserlingk et al., 2013). These pressures are often addressed separately, despite interacting within the same production system.

Yet the same structural transformation that created these pressures also created the conditions to address them.

This report sets out to answer a simple question:

What does genuine circularity look like in dairy, and why does it matter for the Australian industry's future?

The circular economy (CE) provides a practical response to the structural challenges facing Australian dairy. Where a linear system extracts, uses and disposes, a circular system converts waste into inputs, costs into assets, and vulnerabilities into long-term competitive advantage (Ellen MacArthur Foundation, n.d.; DCCEEW, 2024).

For the purposes of this report, circularity is defined as the deliberate redesign of dairy production systems to improve the productivity of the resources already committed to production.

An investment framework for circular dairy production

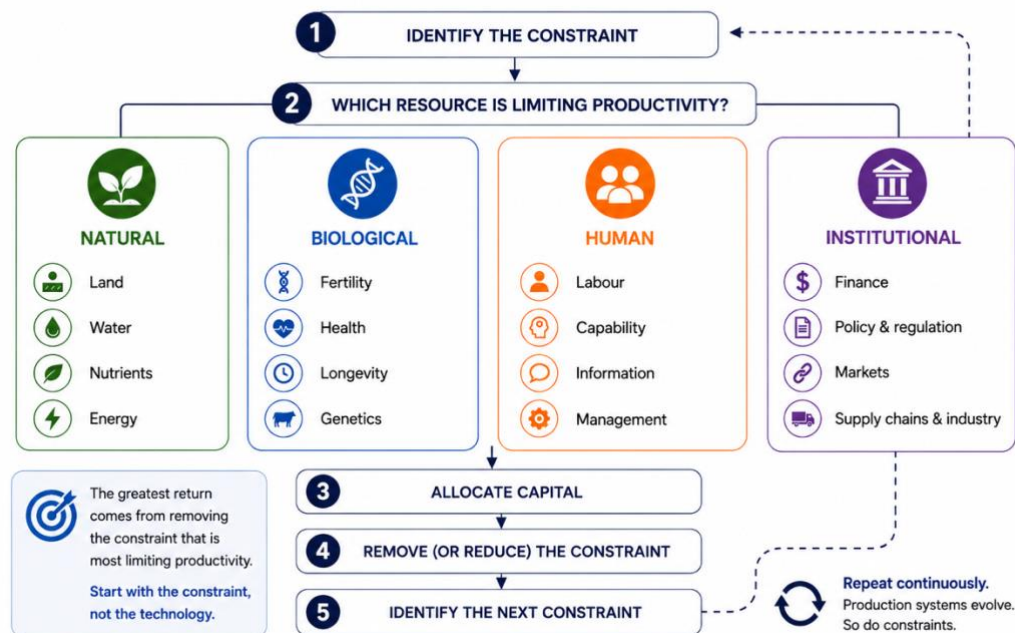


Figure 2. Constraint-led investment framework (Source: Author).

Throughout this report, circularity is considered through a constraint-led investment framework (Figure 2). The framework begins by identifying the resource that most limits productivity, then identifies the intervention required to address that constraint and directs available capital, both time and money, towards it.

Circularity is the next structural productivity reform for Australian dairy. Closing loops is not the objective itself, but the mechanism through which productive assets retain their value for longer, strengthening business resilience, profitability, and long-term competitiveness.

Chapter 1: Closing the natural resource loop

Maximise the value of natural resources already within the system

Land, water, nutrients, and energy are the foundation of every dairy business. In a linear system, these resources flow through the production process in one direction, with outputs leaving the system or remaining underutilised at low value. A circular system treats those outputs as resources whose value can be extended through another productive use.

Natural resources are long-term capital already invested in the business. New inputs, including fertiliser, purchased feed, and grid energy, are continually imported to increase the productivity of those assets. Circularity seeks to generate greater value from existing natural resources, reducing dependence on imported inputs while strengthening business resilience.

The value of natural resources is determined not by how much enters the system, but by how many times those resources create value before leaving it.

How this is achieved depends on the production system. Some businesses recover nutrients, others recycle water, generate renewable energy or integrate biodiversity into production.

Case study: the Van der Schans family, den Eelder, The Netherlands

Voor mens, dier en milieu / For humans, animals, and the environment

The Van der Schans family have farmed den Eelder in the Gelderland province of the Netherlands since 1983, with the first dairy products marketed under the den Eelder brand in 1990. Over four decades, den Eelder has integrated natural resource, nutrient, and energy systems, transforming production constraints into productive assets. Circularity emerged through successive investments rather one transformative project.

The starting point was the farm's natural capital. Heavy clay soils produce grasses whose plant proteins and carbohydrates are largely indigestible to humans. By harvesting these pastures as forage for their Holstein herd, the Van der Schans family transformed a relatively low-value natural resource into high-value dairy products for human consumption. This resource reframing established the philosophy that continues to underpin den Eelder: the greatest opportunities for productivity gains often lie within the constraints of the production system itself.

That philosophy has shaped every subsequent investment. Biodiversity has been integrated into the farming system through the restoration of a plas-dras (Dutch for "puddle-wet") meadow and the establishment of flower strips supporting pollinators and beneficial insects. These investments have improved pasture productivity, strengthened the business's social licence to operate and reinforced the environmental

credentials that support the den Elder brand. Biodiversity has become another productive asset within the farming system, contributing directly to production rather than sitting alongside it.

The same progression is evident in the farm's energy and nutrient systems. Beginning with a mono anaerobic digester in 2012, the system expanded to incorporate processing residues from the factory, recovered heat for pasteurisation, rooftop solar generation, and nutrient recovery through digestate returned to pasture. What began as a manure management system evolved into an integrated farm–factory energy and nutrient system, increasing the productivity of existing assets while reducing dependence on imported energy and synthetic fertiliser.



Figure 3. Circularity at den Elder, robotic TMR barn, biodigester, biodiversity (Source: Arthur and den Elder, 2026).

The den Elder experience shows that circularity is cumulative. Each investment created the foundation for the next: grass became milk, manure became renewable energy, processing residues became biogas, digestate became fertiliser, and biodiversity strengthened the natural capital on which future production depends. Competitive advantage emerged not from a single transformative investment, but from progressively connecting one resource loop to the next.

Key insight: Circularity is cumulative. Successive investment creates the foundation for the next, allowing system benefits to build over time.

Case study: Qatar

لا تتوقف أبداً عن البحث عن الحلقة التالية لإغلاقها / Never stop looking for the next loop to close

Qatar is an Arab peninsula of coral rock and desert sand. The 2017 Gulf blockade fundamentally reshaped its approach to food production and accelerated the push for domestic food security. In an environment defined by extreme heat, negligible rainfall, saline groundwater, and limited arable land, agricultural systems were developed to maximise the value of every available resource.

Water scarcity and food security became recurring themes during visits to Agrico, Baladna Dairy and the Qatar Environment and Energy Research Institute (QEERI) at Hamad Bin Khalifa University (HBKU). Across every organisation visited, circularity was never presented as a sustainability initiative. Conversations consistently returned to economics, food security, and resource productivity.

Environmental outcomes were viewed as a consequence, not an objective. Qatar's system-wide approach to circularity strengthened the resilience of its agricultural businesses while reducing the country's exposure to food price shocks and geopolitical disruption. This context underpinned across every organisation visited, regardless of technology or enterprise.

Established in 2011 **Agrico** has become one of Qatar's largest producers of vegetables by adding one resource loop at a time. Rejected vegetables become livestock feed, discarded timber pallets and production waste organic matter become compost, saline reject water irrigates shelterbelts and mangrove nurseries, nutrient-rich aquaculture water is circulated through mint production before returning to fish production as plant-purified water, and even saline drainage irrigates date palms that support commercial honey production. Agrico succeeds by identifying where value still leaves the business and designing the next resource loop to capture it.

Baladna applies the same philosophy to industrial dairy production. Established in under five weeks in response to the Gulf blockade, the business expanded to a 10,000-cow dairy supplying around 75 per cent of Qatar's domestic fresh milk within just two years. Water underpins the production system, A 20 ML/day reverse osmosis plant converts saline groundwater into process water before wastewater is captured, treated and recycled for barn flushing and cow cooling. Smart Soaker technology is replacing timer-controlled cooling, applying water only when cows are present at the feed bunk which led to a reduction in cooling water consumption by around 60 per cent. Every litre reused is a litre that does not need to be produced again. In this environment circularity is a commercial imperative for one of the dairy's most expensive production inputs.

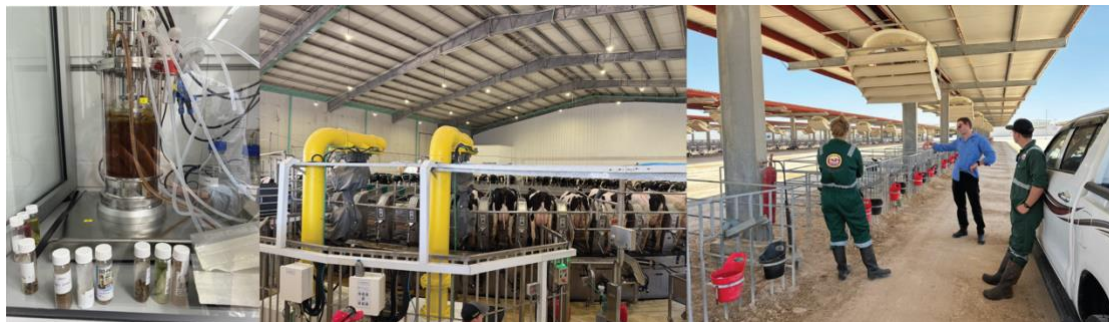


Figure 4. QEERI waste to protein fermentation, Baladna automatic milk preparation technology, discussing calf health with Baladna farm managers (Source: Arthur).

QEERI reinforces a simple principle: no circular solution should become the end point of innovation. Rather than combusting methane from anaerobic digestion to produce energy, researchers are investigating microbial fermentation, using methane to produce high-protein feed for livestock and aquaculture. The protein is fed to the animal, the animal produces manure, the manure feeds the digester, and the digester produces more methane, allowing carbon to remain within the agricultural production system rather than leaving it through combustion. Applied to Qatar's estimated 1.25 million tonnes of annual organic waste, the technology has the potential to produce around 50,000 tonnes of protein-rich animal feed each year.

QEERI approaches waste, energy and feed production as interconnected parts of the same system. Research focuses on identifying the next opportunity to retain resource flows within productive use and increase the value created before they leave the system. This work aligns with Qatar's national priorities in energy, water and environmental resilience, supported by broader investment in applied research through Qatar Foundation and HBKU.

Each Qatari organisation operated at a different point on the same learning curve. Agrico identified overlooked resource loops. Baladna industrialised those loops. QEERI asked how they could create even more value. Demonstrating that circularity is a continual process of identifying the next constraint and redesigning the next resource loop.

Key insight: Circularity is a continual process of redesign. Each intervention changes the production system and reveals the next opportunity for resource productivity.

International observations: nutrient cycling

Nitrogen, phosphorus and potassium (NPK) are among the most valuable natural resources within a dairy production system. They move from the soil through pasture, feed and livestock before the remaining nutrients become organic waste. Nutrient cycling extends the productive life of those nutrients by returning them to productive agriculture, reducing reliance on purchased fertiliser while increasing the value created from natural resources already within the system.

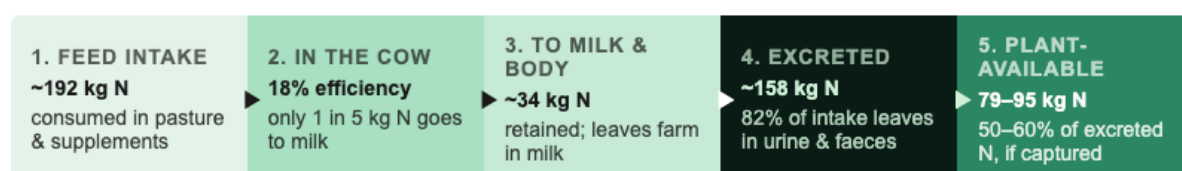


Figure 5. The Nitrogen Journey: from paddock to (Source: Arthur, based on Humphreys et al., 2020; Aarons et al., 2020).

NB extrapolated workings can be found in Appendix A to this report.

An integrated agribusiness visited in the Philippines demonstrated how nutrient cycling can be designed across multiple complementary enterprises. Nadine's egg-laying enterprise, Juliana's cattle operation, Greenland Organic Fertilisers, and Platinum Mill were designed to exchange resources, maximising nutrient retention throughout the production system. Chicken litter from approximately 18 million laying hens is collected beneath bamboo-slatted sheds and kept dry to minimise ammonia losses before being processed into certified organic fertiliser. Organic waste from the cattle enterprise is returned directly to the land, supporting silage and fodder production, while feed manufactured by the feed mill returns nutrients to the livestock enterprises. Rather than leaving the production system as waste, nutrients circulate between enterprises.

At **Melkveebedrijf van Steenberg** (Henrie's) in the Netherlands, a permanently housed Holstein herd generates a continuous slurry stream. Progressive tightening of manure management under the Dutch Meststoffenwet (Fertilisers Act), together with the 2023–2025 phase-out of the Netherlands' EU Nitrates Directive derogation, has driven investment in a €330,000 Farmcubes Quadro 1 nutrient recovery system. The Quadro 1 separates slurry into solid and liquid fractions before stripping ammonia from the liquid fraction and converting it into a concentrated RENURE nitrogen fertiliser, while concentrating phosphorus in the solid fraction. The Farmcubes Quadro 1 increases the precision, flexibility and value of nutrients already within the manure stream, transforming slurry from a manure management challenge into a portfolio of higher-value nutrient products.

The solid fraction creates further value within the production system. After pasteurisation, the separated fibre is reused as bedding for the milking herd, eliminating the need to import sand while providing a softer, more comfortable resting surface than mattresses. Rather than managing slurry as a single waste stream, Henrie has effectively refined it into multiple higher-value products: precision nitrogen fertiliser, concentrated phosphorus and recycled bedding.

The production system intervention is entirely different at Tom and Sophie Gregor's predominantly pasture-based dairy **Home Farm** in South West England. Rather than mechanically separating nutrients, organic waste generated from the milking herd, winter housing and straw bedding is composted with fungal inoculants before being mixed with water and applied through irrigation to stimulate soil biology and progressively improve the soil's natural capacity to cycle nutrients.

Although these businesses operate in very different environments, they each illustrate the same principle. Production system design determines how nutrient cycling is achieved. The technologies differ because the production systems differ. Regardless of technology, nutrient flows must be directed to where they create the greatest productive value.

Key insight: Nutrient cycling extends the productive life of nutrients, reducing dependence on imported inputs and increasing returns from existing resources.

Discussion - implications for Australian dairy

The commercial opportunity presented by natural resource circularity is substantial, but it is not uniform across Australian dairy. The value created depends on production scale, resource concentration and the constraints limiting productivity within each business.

Many Australian dairies already apply many principles of natural resource circularity. Effluent is returned to paddocks, rainfall and farm wastewater are captured and reused, and on-farm solar generation is becoming increasingly common (DA, 2024c).

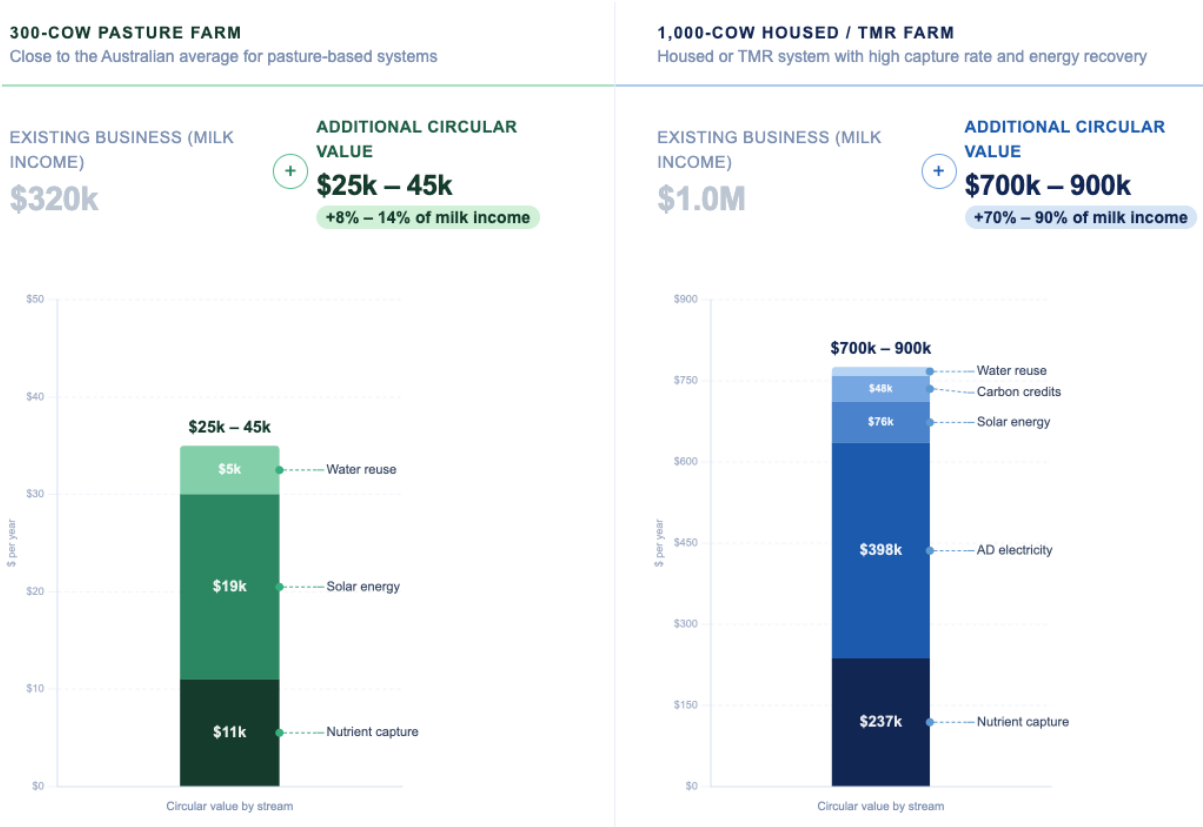


Figure 6. The circular opportunity within existing resources. Estimated annual circular economy value by practice, compared to farm cash income — 300-cow pasture and 1,000-cow housed/TMR dairy farm, Australia (2025–26 prices). (Source: Author, based on Humphreys et al., 2020; Aarons et al., 2020).

NB author working included as part of Appendix A to this report.

In some businesses this may be achieved through simple investments that improve water reuse, nutrient management or energy recovery. In others, more advanced technologies such as anaerobic digestion, advanced nutrient recovery or water treatment become commercially justified because they unlock value that would otherwise remain unrealised. In every system, the appropriate investment is determined not by the technology itself, but by the constraint limiting productive value within the business.

The commercial viability of natural resource circularity is determined as much by the investment environment as the technology itself. Different policy settings create different investment decisions. Environmental regulation in Europe, water scarcity and Qatar's food security strategy each changed the commercial return on investments such as anaerobic digestion, nutrient recovery and water recycling.

Australian dairy operates within a different investment environment, where many of these technologies must compete directly with investments that improve production efficiency. If circular technologies are expected to contribute to Australia's future productivity, emissions reduction and renewable energy generation, industry requires a clear and enduring policy framework that provides confidence for long-term

investment. Without investment confidence, capital will continue to favour investments delivering faster and more predictable returns.

The investment pathway will differ with production intensity. Predominantly pasture-based dairies are likely to realise the strongest returns from efficient effluent capture, storage and redistribution, while more intensive systems create concentrated resource streams that can justify higher-value recovery and processing technologies.

Building the Australian evidence base around the commercial performance of circular technologies across different scales, production systems and environments will give businesses greater confidence to invest where sustained returns can be realised. Australia's competitive advantage will depend less on discovering new technologies than on identifying where existing technologies remove the production constraints that limit productive value.

Chapter 2: Closing the biological loop

Maximise the value of animals already within the system

The herd is a productive asset that creates, loses and regenerates value throughout its lifetime. Genetics create biological potential and production systems determine how much of that potential becomes productive value. Once the herd enters production, the objective is to maximise the lifetime return generated from that biological capital.

Improving fertility, longevity, and animal health increases the return from the herd already within the business while lifting the productivity of every other investment. Decades of genetic improvement have banked substantial biological potential into modern dairy herds. The commercial objective is to maximise the lifetime return generated from every animal retained within the herd.

Some production systems realise greater productive value by adapting the production environment to the animal, others adapt the animal to the production environment. Both seek to maximise the lifetime value generated from the herd. They do so by responding to different production constraints. Biological performance is determined as much by production system design as by the animal itself.

Milk is only one component of how farms realise biological value. Genetic improvement through AI and breeding programs, dairy-beef integration, replacement stock and stud sales create additional value from the same biological asset. The objective is to maximise the lifetime return generated from every animal by extending productive life and creating value at multiple points throughout it.

Case study: Lea Manor Dairy, Eaton Estate, Grosvenor Farms, UK

Virtus non stemma / "To be the best producer of milk in the UK whilst farming in an environmentally and socially sustainable way"

One of the United Kingdom's largest and most productive dairies (Balsom, 2024), Lea Manor Dairy on the Eaton Estate, Cheshire is the culmination of more than six centuries of agricultural and environmental stewardship. Opened in 2014, Lea Manor Dairy consolidated four separate herds from across the estate and now milks more than 2,600 Holstein cows.

Circularity underpins Grosvenor Farms' farming philosophy, with the business viewing itself as an integrated ecosystem where animal welfare, environmental stewardship, technology and people work together to improve the performance of the production system. Years of planning and system design preceded the dairy's development, grounded in the belief that greater productive value could be realised from the same herd by designing the production system around the needs of the cow.

The investment was driven by a vision broader than increasing milk production alone. Grosvenor Farms sought to create a more self-sustaining farming system that simultaneously realised more of the herd's genetic potential, improved animal welfare

and strengthened environmental stewardship across its 2,340-hectare mixed farming enterprise. The production system was designed to remove the constraints limiting animal performance, recognising that greater productivity, healthier cows and improved natural resource outcomes could be achieved together rather than as competing objectives.

Every component of the production system contributes towards that objective. Freestall barns provide more space per cow than is typical, while deep sand bedding, rarely used within the United Kingdom, was selected for its superior comfort and hygiene. External feed passages protect cows from the weather while allowing natural light and fresh air into the barns, supported by mechanical ventilation that maintains a consistent environment throughout the year.

High-quality forage is produced across the estate and complemented with locally sourced food by-products, including bread residues and Trafford Gold brewers' grains, replacing imported soybean meal. Genetic improvement continues beyond milk production, with feed conversion efficiency now incorporated into breeding decisions through EcoFeed, a genomic breeding value that identifies animals capable of producing the same output from fewer feed resources. The herd currently achieves a feed conversion rate of approximately 0.47 kg of feed per litre of milk, demonstrating how genetics, nutrition and management have been integrated to maximise the productive value realised from each animal. No single decision transformed herd performance. Each design decision removed another constraint on biological performance. Competitive advantage emerged from the cumulative effect of those decisions, not from any single innovation.



Figure 7. Lea Manor Dairy, Eaton Estate effluent management, core values, freestall design, and biodiversity (Source: Arthur).

The benefits extend well beyond milk production. The integrated production system has enabled a 50% reduction in antibiotic use, with blanket dry cow therapy no longer required despite some cows being dried off while still producing more than 40 litres of milk per day. Average production exceeds 12,300 litres per cow annually, demonstrating that reduced antibiotic use has been achieved alongside exceptionally high production. Approximately 85% of forage production is supported through recycled manure nutrients, with no imported phosphorus or potassium fertiliser applied for more than fifteen years.

This strategy has supported Grosvenor Farms' pursuit of greater input independence, with all fodder grown on the estate. Renewable energy generation and planned anaerobic digestion continue that progression, while approximately 12% of the estate

is managed for biodiversity and environmental stewardship. These initiatives contributed to a 40% reduction in carbon intensity over the past decade (Balsom, 2024).

Lea Manor shows that maximising the lifetime value generated from the herd extends well beyond milk production. Designing the production system around the needs of the animal strengthened the productivity of the wider farming enterprise, creating complementary gains in animal welfare, resource efficiency and environmental stewardship. Biological performance became a function of system design, not genetics alone.

Key insight: The greatest gains came from removing the constraints preventing the herd from expressing its biological potential.

Case study: The KiwiCross, New Zealand

Manaaki whenua, manaaki tangata, haere whakamua / Care for the land, care for the people, go forward

New Zealand has built one of the world's most competitive dairy industries by adapting its national herd to the production environment. Through decades of coordinated genetic selection, the Kiwicross cow emerged as an animal specifically developed for New Zealand's production environment, predominantly combining Holstein-Friesian and Jersey genetics. Importantly, the breeding objective extended beyond the farm gate. New Zealand's export-oriented processing sector places greater value on milk solids than liquid milk volume, creating strong commercial incentives to breed cows capable of efficiently converting grazed pasture into fat and protein. The result was a cow capable of walking long distances, grazing steep hill country, performing under wet seasonal conditions and converting seasonal pasture into the products most valued by the supply chain. This alignment between breeding objectives, farm systems and processing capability has reshaped the biological characteristics of the national herd over successive generations.

The philosophy was evident at **Tiroroa**, the dairy farm of Tracy and Wynn Brown. Seasonal calving aligned feed demand with pasture growth, while cows were dried off early during drier seasons to preserve body condition and reproductive performance rather than maximise short-term milk production. The business remained largely self-sufficient in feed production through home-grown maize and pasture, reducing exposure to purchased feed markets. Environmental stewardship formed part of the same production philosophy, with waterways fenced, wetlands restored to improve water quality, steeper country retired into forestry and biodiversity plantings, and nutrients recycled through targeted effluent management. Productivity, profitability and environmental stewardship were not viewed as competing objectives. As Tracy observed, "You can't be green if you're not in the black."



Figure 8. New Zealand Dairy, LIC genetic testing, effluent management and nature restoration at Tirora (Source: Arthur).

The New Zealand dairy industry shows that the animal loop is strengthened by increasing the value generated from biological resources already within the herd. Genetic improvement increased the productive value of the national herd while farm management, processing capability and market incentives evolved alongside it. Biological value emerged because genetics, production systems and market requirements evolved together. New Zealand did not breed a better cow. It bred a cow better suited to its competitive advantage.

Key insight: The greatest gains came from aligning herd genetics with the farming environment.

Discussion – What is the opportunity for Australian dairy?

Australian dairy is characterised by significant heterogeneity in both its production systems and the philosophies that underpin them. Climatic, environmental and economic conditions have given rise to a spectrum of production systems, ranging from predominantly pasture-based grazing enterprises to mixed farming, partial mixed ration and increasingly fully housed systems. DA's recent revision of its national feed system classifications recognises this diversity. There is no single model of circularity capable of maximising productive value across every Australian dairy business. The most appropriate investments are guided by the production system, management philosophy and constraints of the individual business.

The herd represents one of the largest biological capital investments within a dairy business, and unrealised biological potential carries a substantial commercial cost. Improvements in fertility, feed conversion efficiency, longevity and animal health increase not only the lifetime value of the herd, but the return generated from land, feed, labour, infrastructure and energy already committed to production. DA's InCalf program estimates that improving reproductive performance above industry benchmark levels alone represents more than \$110 million in additional annual value to the Australian dairy industry (DA, n.d.).

Australian dairy already reflects a range of approaches to increasing biological value. Registered breeding programs and elite genetics continue to increase the productive potential of the national herd, while crossbreeding is increasingly used to target

characteristics such as fertility, longevity, health and milk components across a range of production systems. Dairy-beef breeding creates another source of value by producing calves for beef markets, reducing the number of low-value dairy calves and limiting exposure to volatile dairy heifer export markets. Genomic testing, breeding values and herd performance data increasingly allow these decisions to be based on measured biological and commercial performance rather than assumption. The objective is not a particular breed or breeding strategy, but a herd better aligned with the production system and the markets it serves.

The strategic challenge for Australian dairy is determining where the next investment will generate the greatest increase in lifetime biological value. For some businesses that investment will be genetics. For others it will be nutrition, reproduction, infrastructure, management or market alignment. Investment should focus on the constraints limiting biological performance to increase the return generated from the herd already within the business.

Chapter 3: Closing the people loop

Maximise the value of work of human capital

Every dairy business depends on human capital. Knowledge, skill, passion, judgement and leadership determine how effectively natural and biological resources are converted into productive value.

Australian dairy businesses face one of their greatest structural constraints in human capital. In 2024, 42% of Australian dairy farms employed migrant labour, more than double the 18% recorded in 2020, while 70% of farmers reported difficulty recruiting staff. In some of Australia's traditional dairying regions, unemployment hovers around just 1%, leaving little domestic workforce available to fill vacant positions. The structural challenge is further exposed by a workforce with an average age over 55 (DA, 2024b; ADF and DA, 2024).

To sustain production, many dairy businesses have become increasingly reliant on family labour, migrant workers and labour mobility programmes such as the Dairy Industry Labour Agreement (DILA) and the Pacific Australia Labour Mobility (PALM) scheme. These approaches increase labour supply but do not remove the underlying production constraint. Businesses remain susceptible to continual recruitment, onboarding and workforce turnover rather than increasing the value generated from the human capital already within the business. Rising visa costs, regulatory compliance and administrative complexity further reduce their effectiveness over time.

People have become a defining constraint on the future productivity of Australian dairy. Circularity creates an opportunity to redesign production systems around how people create value, building farm environments that extend their capability, judgement and impact.

Case study: recovering higher-value work through automation

Human capital on dairy farms is disproportionately consumed by repetitive, time-critical and physically demanding tasks. Cows must be milked at predetermined times, calves fed, and many of the most time-critical tasks cannot simply be shortened. As a result, higher-value activities such as staff training, herd management, preventative maintenance and business improvement are continually pushed behind operational priorities, often becoming tasks completed outside normal working hours.

Circularity redesigns production systems to automate repetitive work that dictates the rhythm of the working day, creating the time and capacity for people to undertake higher-value tasks.

At **Dillington Estate, Somerset, United Kingdom**, six robotic milking units transformed the daily role of the dairy team. Fixed morning and evening milking routines were replaced by management of a voluntary milking system, enabling staff to spend more time improving genetics, forage production and overall herd

performance. Average milking frequency increased to 3.2 milkings per cow per day, contributing to higher milk production while creating a more attractive and flexible working environment. The most significant outcome was not that fewer people were required, but that the same people created greater value.

Fundo El Risquillo, Chile, the world's largest voluntary robotic dairy, demonstrated that business growth does not require proportional growth in labour. In 2014 the business started to consolidate 6,500 cows from across two sites into a single highly automated operation, replacing conventional rotary dairies with robotic. Today, approximately 70 robotic milking units form the centrepiece of the operation.

Robotics formed only one component of a broader circular production system. Automated cow movement, precision feeding, integrated manure management, irrigated fodder production and a strong emphasis on cow comfort transferred routine operational work to the production system. New barns were intentionally stocked below capacity, housing around 50 cows in facilities designed for 60, reflecting the philosophy that "the cows are the bosses" and recognising that biological performance ultimately determines business performance.

Average production exceeds 46 litres per cow per day, with cows voluntarily milking 3.1 times per day. Rather than business growth requiring proportionally more labour, circularity reduced the labour required per cow by 28%, enabling herd expansion while developing a smaller, more specialised workforce focused on biological performance, system optimisation and continual improvement. Labour productivity improved because routine work became a system capability rather than an individual responsibility.

At **GAEC du Clos Roset, Normandy, France**, robotic milking removed the constraint of fixed, repetitive milking routines, creating additional management capacity within the business. Farmer Arnaud Fossey reinvested that capacity into activities strengthening both the business and the wider dairy industry. As President of the Isigny Sainte-Mère Cooperative, his leadership helps shape the future competitiveness of one of France's most recognised dairy regions.

Central to this philosophy was *terroir*. More than the characteristics of soil and climate, *terroir* reflected the relationship between landscape, farming systems, people and product quality that underpins the international reputation of Isigny dairy products. Recovered management capacity supported apple production, strengthened biodiversity and reduced reliance on a single enterprise. The same management capacity also enabled leadership beyond the farm gate, strengthening the cooperative responsible for creating value across the wider region. Human capital created value at multiple scales, from the farm business to the regional dairy industry.



Figure 9. Robotic dairying: Dillington Estate, United Kingdom, Fundo El Risquillo, Chile, and Meerings, The Netherlands (Source: Arthur).

Case study: recovering high-value work through better decision making

Data has become one of the most abundant yet underutilised assets within modern dairy systems. Circularity improves how human capital uses information. Decision-support technologies create value by reducing the time spent coordinating routine management activities while improving the quality, consistency and speed of decision-making.

At **Home Farm, south-west England**, artificial intelligence is integrated into day-to-day management. Sophie Gregory uses ChatGPT into the day-to-day management of the dairy business, using it to support communication, develop standard operating procedures and assist with planning. This reduces the time required to coordinate daily, weekly and seasonal activities, ensuring every team member understands priorities and has the information required to perform their role effectively.

The management capacity recovered through these interventions is invested back into higher-value activities that strengthen both the business and the wider dairy industry. Sophie sits on the Arla Board of Representatives, helping shape the future direction of one of the world's largest dairy cooperatives. Through her **@farmer_in_training** Instagram account and co-hosting the **Meet the Farmers – The Big Debate** podcast, she improves public understanding of dairy farming and strengthens knowledge exchange across the agricultural industry.

Koepon, the Netherlands, illustrates the cumulative effect of integrating multiple circular interventions within a single production system. Robotics, automation, precision agriculture and genetics reinforce one another, increasing the value created by the same human capital.

Robotic milking removes much of the repetitive operational work from the dairy, while automated manure removal reduces the labour intensity of daily cleaning and improves consistency within the barn. Integrated precision management through Lely Horizon combines robotic milking, cow-level feeding, health monitoring and performance data to support nutritional and management decisions with minimal manual intervention. GPS-guided machinery improves the efficiency of fodder production, while genomic selection and performance recording continually strengthen biological performance. Individually, these technologies improve discrete parts of the business. Together, they

create an integrated production system in which routine work and decision-making are increasingly embedded within technology.

This integration allows people to focus more heavily on genetics, nutrition, system performance and continual improvement. Koepon's genetics business demonstrates how that capability can create value beyond milk production itself. Genomic selection and breeding decisions are used to develop elite animals and AI sires, with Koepon-bred genetics marketed into dairy herds internationally.

At Koepon, the role of labour shifted accordingly. Robots handled much of the routine work, while people focused on genetics, nutrition and system performance. The technology did not replace human capability; it created the capacity for that capability to generate value at a higher level.

No individual technology transformed Koepon. Competitive advantage emerged from integrating technologies in a way that shifted human capital away from repetitive work and towards the activities where knowledge and judgement create the greatest value.

Discussion – rethinking human capital in Australian dairy

Human capital creates greater value when less time is consumed by repetitive operational tasks. This allows people to focus on analysing information, making decisions, improving natural and biological resource performance, strengthening business systems and contributing beyond the farm gate.

Australian dairy has largely designed production systems around labour requirements rather than acknowledging how human capital creates value. Smaller farming businesses often respond by stretching family labour across operational, managerial and strategic responsibilities required to sustain production, while larger businesses have traditionally achieved growth by increasing workforce size, labour specialisation and organisational complexity. Both models sustain production. Neither changes how human capital optimises value.

Circular approaches redesign routine operational work so that automation and precision management support people rather than dictate how they work. Human capital is redirected towards activities that improve natural resource and biological performance, strengthen business resilience and strengthen competitive advantage.

Australian dairy production systems were largely developed around family-operated farms in traditional dairying regions, where labour, knowledge and support networks were concentrated locally. Today's businesses are larger, more dispersed and more organisationally complex, yet human capital is often still allocated according to assumptions formed under that earlier model. Circularity provides an opportunity to redesign production systems around how people create value, with technology integrated to support that redesign.

The right circular investment depends on what constrains value creation. For many smaller dairy businesses, labour is not the primary constraint. Management capacity is. Owner-managers frequently possess the knowledge required to improve productivity, profitability and resilience, yet remain responsible for operational,

managerial and strategic decision-making across the entire business. Circular interventions that strengthen management capability are therefore likely to deliver the greatest return.

Technologies such as individual animal identification, milk metering, genomic testing, SenseHub, HerdVision, decision-support software and artificial intelligence strengthen management capability by improving the quality, consistency and speed of decision-making. More capital-intensive interventions, including robotic milking, virtual fencing and housing systems, become appropriate where they align with infrastructure renewal, business scale and business strategy rather than technology adoption alone. Regardless of scale, the investment objective is increasing the value created by the human capital already committed to the business.

As dairy businesses grow, managing organisational complexity becomes as important as managing cows. Larger herds often require more specialised labour, additional management layers and greater coordination, while also increasing exposure to regulatory, tax, employment and compliance obligations. These requirements add cost, consume management time and increase business risk. Where operational knowledge remains concentrated within individuals, staff turnover can also remove institutional knowledge that is difficult to replace. Circular production systems can reduce this complexity by embedding greater consistency within routines, systems and technology, allowing people to focus on biological performance, resource management and higher-value decisions.

Australian dairy carries some of the highest labour costs of any export-oriented dairy country in the world (Beca, 2021; Higgins, 2025). Circularity changes how labour creates value, even if it cannot solve labour shortages on its own. As milk production has contracted, manufacturing utilisation has declined, increasing pressure on processors, regional employment and Australia's future competitiveness. These structural challenges cannot be solved through labour supply alone. Australia's future competitiveness depends on production systems that create greater value from the people already committed to the industry. Strengthening human capital improves individual farm performance while also supporting a more resilient milk supply, stronger regional manufacturing, more competitive export industries and more thriving regional communities. Circularity provides a practical framework for redesigning work around how people create value rather than how labour is supplied.

Chapter 4: The enabling environment

Building confidence, coordination and capability

Every circular production system begins with a defined objective and an investment decision. Businesses commit capital because they believe redesigning their production system will create greater value over time. That decision depends on the environment in which it is made: one that builds confidence, aligns incentives across the supply chain and gives businesses a practical pathway for investment.

Australian dairy has already demonstrated how industry can successfully accelerate production system change. Following the record milk prices experienced during 2022–23 (DA, 2023), and as seasonal conditions stabilised after several years of drought and market disruption, many dairy businesses regained the confidence and capital to invest. At the same time, DA developed practical housing guidelines, Australian case studies and decision-support resources that gave farmers confidence to evaluate housed systems within their own businesses.

The convergence of favourable market conditions, practical industry leadership and a clear investment framework enabled housed dairy systems to move rapidly from an emerging concept to mainstream consideration across Australian dairy. That adoption has been driven by multiple constraints within existing production systems. Larger herds, tighter labour availability and greater climate variability have increased the value of controlling feed intake, cow comfort, animal movement and effluent management within a more consistent production environment. For some businesses, housing has also made automation and expansion easier to integrate. The shift therefore reflects a broader response to labour, climate and production risk, rather than simply a move away from grazing.

The same conditions now exist for circular production. Many of the technologies, management approaches, and production systems required to redesign Australian dairy businesses already exist, yet they continue to be discussed through separate lenses of productivity, sustainability, emissions reduction, animal welfare, and business resilience. This fragmentation reinforces the perception that productivity, environmental performance and business resilience require competing investment decisions. A different investment framework is required, one that reconnects these objectives within a single production system, allowing each investment to strengthen productivity, environmental performance and business resilience together.

Financial capital, management capacity and time are finite, meaning every investment competes for the same resources. The commercial question is not whether an investment is circular, but whether it generates the strongest return from the resources already committed to the business.

Farmers invest within the environment created around them. Processors, banks, governments, industry organisations and consumers all influence whether businesses have the confidence to invest. When policy and market signals are consistent, investment confidence grows. When priorities are fragmented or uncertain, businesses

defer investment. Circular system redesign therefore depends on both individual farm businesses and an enabling environment that supports long-term investment.

Investment confidence depends on policy settings that are stable, coherent and supportive of productive agriculture. Dairy businesses make investment decisions across decades, yet the policies shaping those decisions can change much more quickly. Policy should provide businesses with a predictable operating environment while balancing competing demands for land, water, energy and environmental outcomes. In the Murray–Darling Basin, for example, water policy must balance the long-term health of the river system with the productive value created by irrigated agriculture and the communities it supports.

Land-use and energy policy face a similar challenge, ensuring renewable generation and transmission infrastructure can be developed without unnecessarily displacing productive agricultural land or imposing disproportionate costs on regional communities. Good policy does not remove competing interests, it establishes rules through which those interests can coexist, and businesses can continue to invest with confidence.

Banks do not simply finance Australian agriculture; they influence how Australian agriculture develops. Every lending decision shapes the businesses that will operate over the next twenty or thirty years. If circular investments improve business resilience, resource productivity and environmental performance, lending frameworks should increasingly recognise these characteristics when assessing investment. Banks already differentiate lending according to risk, security and asset quality. Production system design also influences business performance and risk, yet these characteristics are rarely recognised explicitly within lending frameworks. Financing approaches that recognise stronger resource productivity, resilience and business performance would strengthen investment confidence while directing capital towards more productive businesses.

Value created on farm must also be recognised beyond the farm gate. Circular production systems can create value across the dairy supply chain through stronger marketability, greater supply resilience and new manufacturing opportunities. Yet the investment required to create these outcomes is often concentrated at farm level. FrieslandCampina's Foqus Planet programme demonstrates how supply chains can recognise and reward this value through milk price premiums linked to independently verified on-farm performance across greenhouse gas emissions, biodiversity, animal welfare and responsible resource management.

The strongest incentives are created when businesses investing in capability also share in the value that investment creates. This matters as Australia's declining milk pool continues to put pressure on processor utilisation and profitability. In response, much of the industry has focused on factory closures, processing consolidation and production efficiency. While this can lower costs, it also removes capability. Once regional processing capacity, skilled people and specialised infrastructure are lost, they are difficult and expensive to replace.



Table Sustainable development 2026

Themes	Indicators	Threshold value (start of bonus)	Bonuses				Top value (maximum bonus per 100 kg of milk)
ANIMAL HEALTH AND WELFARE	Longevity (years + months + days)	€0.00	5 years and 4 months			7 years and 2 months	€0.10
	Calf rearing (KalfOK)	€0.00	75 points			95 points	€0.10
CLIMATE	Greenhouse gas emission (gram CO ₂ -eq/kg milk)	€0.00	925 g CO ₂ -eq			700 g CO ₂ -eq	€1.50
BIODIVERSITY	Nitrogen farm balance (kg N/ha)	€0.00	225 kg N/ha			40 kg N/ha	€0.30
	Protein from own land (% of total protein used)	€0.00	50%			80%	€0.30
	Nature & Landscape (% total surface)	€0.00	10%			50%	€0.40
GRAZING	Grazing	€0.00	Partial grazing €0.40		Full grazing €1.30		

Figure 10. FrieslandCampina Fokus Planet Table Sustainable development 2026 (Source: FrieslandCampina, 2026).

The opportunity for Australian dairy is not simply to process a smaller milk pool more efficiently, but to create more value from it. That requires investment in differentiated products, specialised processing and higher-value manufacturing. Consolidation may improve the cost base, but without parallel investment in processing capability and product development, it risks improving efficiency without improving value.

Australian dairy currently lacks a shared framework for circular production system design. Farmers are presented with opportunities to improve productivity, reduce emissions, strengthen animal welfare, enhance biodiversity and build business resilience, yet these objectives are commonly discussed through separate programs, funding streams and advisory services. The industry already possesses much of the knowledge and technology required. What it lacks is a clear investment pathway that brings these objectives together around value creation. DA's housing framework showed how practical guidance can accelerate production system change. Australian dairy now requires an equivalent framework that helps businesses identify, evaluate and implement circular investments appropriate to their own circumstances.

Australian dairy has repeatedly demonstrated its capacity to redesign production systems when confidence, practical guidance and commercial incentives align. The remaining challenge is to create an environment in which capital, policy and industry support flow towards production systems that generate greater value from natural resources, biological capital and human capability.

Conclusions

Circularity is not defined by a particular technology, production system or scale. Productive businesses respond to their own constraints by redesigning how land, water, livestock, people and capital work together.

Future productivity gains will come increasingly from improving the interaction between these resources, rather than treating each one in isolation. Natural resources create greater value when nutrients, water and energy remain productive for longer. Biological capital creates greater value when production systems allow animals to realise more of their lifetime potential. Human capability creates greater value when people can focus on judgement, management and continual improvement.

Australian dairy has already demonstrated its capacity to adapt through deregulation, consolidation, mechanisation and genetic improvement. The next stage is production system redesign: directing investment towards the constraints limiting each business and creating greater value from the resources already within it. Beyond efficiency, this is where Australia's next competitive advantage lies.

Recommendations

Recommendation 1

Develop national guidelines for circular dairy production system design

Lead: Dairy Australia

Supporting: Australian Dairy Farmers, processors, universities, consultants

Recommendation

Develop nationally recognised guidelines for Circular Dairy Production System Design that help Australian dairy businesses identify production constraints and evaluate circular investments. Building on the success of DA's Housing Guidelines, integrate natural resources, biological resources and human capital within a single investment framework.

Key actions

1. Develop practical decision-support tools for production system redesign.
2. Publish Australian investment case studies demonstrating successful circular production systems.
3. Update technical guidance as technologies and farming systems evolve.
4. Develop implementation guidance that integrates technology adoption with workforce capability, management systems and operational redesign.
5. Build an Australian evidence base by monitoring industry adoption and business performance.

Recommendation 2

Create a policy environment that encourages long-term investment and protects productive agricultural capacity

Lead: Australian Government

Supporting: State Governments, Local Government

Recommendation

Reduce regulatory complexity and provide the long-term policy certainty required for businesses to invest confidently in circular production systems.

Key actions

1. Reduce regulatory and planning complexity for productive farm investment, including duplication across environmental and development approvals.
2. Provide stable long-term settings for water, energy, taxation, employment, and emissions, while maintaining productive access to land and water for food production and regional communities.
3. Embed agricultural production and processing capability within national food security and sovereign capability policy, recognising them as strategic assets.
4. Extend government investment and finance programs to circular farm infrastructure that improves resource productivity, resilience, and environmental performance.

Recommendation 3

Align agricultural finance with long-term value creation

Lead: Australian banks

Supporting: Clean Energy Finance Corporation, Australian Government, Dairy Australia

Recommendation

Lending frameworks should recognise investments that strengthen long-term business resilience by improving the productivity of natural resources, biological capital and human capability.

Key actions

1. Expand existing sustainable finance products to support whole-of-system circular production investments, not only prescribed environmental projects or assets.
2. Provide meaningful financial incentives from within lending margins for investments that demonstrably improve resource productivity, resilience and long-term business performance.
3. Recognise measurable improvements in production-system resilience and business risk within credit assessment, lending terms and pricing.

Recommendation 4

Reward value creation across the dairy supply chain

Lead: Dairy processors

Supporting: Dairy Australia, Austrade, retailers, exporters

Recommendation

Develop commercial mechanisms that allow farm businesses investing in productive capability to share in the value those investments create across the dairy supply chain.

Key actions

1. Develop transparent supply agreements that recognise circular production system investment.
2. Increase investment in specialised processing, product development and higher-value manufacturing to create greater value from Australia's milk pool.
3. Strengthen export development and market access for differentiated, higher-value Australian dairy products.
4. Co-invest with farmers in innovations that create shared value across the supply chain.

Recommendation 5

Embed circular production system design within Australia's future dairy strategy

Lead: Dairy Australia

Supporting: Australian Government, universities, research organisations

Recommendation

Recognise circular production system design as the next productivity framework for Australian dairy and embed it within future industry strategy, research, extension and education.

Key actions

1. Embed circular production system design within future industry strategy.
2. Align research, extension and education around whole-of-system dairy design.
3. Integrate circular production system design into tertiary education, extension and professional development.
4. Support multidisciplinary research into whole-of-system dairy design.
5. Build workforce capability in systems thinking, digital agriculture and production system management so businesses can realise the full value of automation and emerging technologies.

Closing statement

Circularity will not be driven by individual technologies or isolated farm innovations. It will emerge when investment, policy, finance and supply chains all reward the same outcome: creating greater value from the natural resources, biological capital and human capability already committed to production.

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Appendices

Appendix A.1 – nutrient flow workings

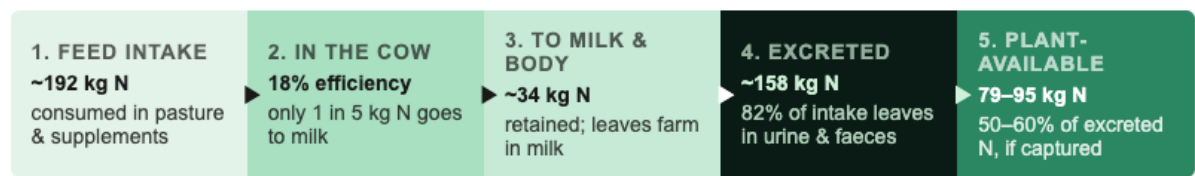


Figure A.1.1. The Nitrogen Journey: from paddock to (Source: Arthur).

Table A.1 — Nutrient Mass Balance: Intake, Retention and Excretion per Dairy Cow

Nutrient	Feed	Retained in milk & body		Excreted in manure		Plant-available from manure*	
	Intake (kg/cow/yr)	kg/cow/yr	% of intake	kg/cow/yr	% of intake	% of excreted	kg/cow/yr
Nitrogen (N) Protein, amino acids	~192	~34	~18%	~158	~82%	50–60%	79–95
Phosphorus (P) Bone, cell membranes	~29	~7	~25%	~22	~75%	80–90%	18–20
Potassium (K) Osmotic balance, pasture	~137	~12	~9%	~125	~91%	~90%	~112

Source: Humphreys et al. (2020), *Animals*, PMC7143236; Aarons, Gourley & Powell (2020), *Animals*, vol. 10, no. 3; NC State Extension (2022). (Source: Aurther).

*Plant availability from collected manure; assumes standard surface application or lagoon storage. Incorporation within 48 hours improves N availability to ~70–80% through reduced volatilisation.

Note on N forms: Of excreted N, approximately half is urinary-N (urea → ammonium, 70–90% plant-available); half is faecal organic-N (~30–40% plant-available in year one, with further release in subsequent years). P and K in manure are effectively fully available in year of application.

🔄 The table above reveals a striking inefficiency: **dairy cows convert only 18% of dietary nitrogen into milk**. The remaining 82% is excreted — yet of that excreted nitrogen, 50–60% is plant-available if captured. This means that for every 100 kg of N fed, approximately **13–15 kg is recoverable as fertiliser** even in conventional systems. In housed or high-input systems where capture rates reach 70–90%, that recoverable fraction rises sharply — making production system design the central variable, not the biology of the cow.

Table A.2 — Capture Rate by Production System

PASTURE-BASED (SYSTEM 1–2) 10–15% Shed washdown & bail effluent only. Grazing deposition unrecoverable. Of 158 kg N excreted, ~16–24 kg is capturable.	MIXED / BAIL-FED (SYSTEM 3–4) 20–35% Increased yard time improves capture. Of 158 kg N excreted, ~32–55 kg is capturable.	HOUSED / FREESTALL TMR (SYSTEM 5) 70–90% Fully collected manure & slurry system. Of 158 kg N excreted, ~111–142 kg is capturable — enabling full circular loop.
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Capture rate estimates based on DA effluent guidelines and author's synthesis. System classifications follow DA's five-system framework.

Table A.3 — Combined N+P Fertiliser Replacement Value from Captured Manure

Production system	N captured (kg/cow/yr)	P captured (kg/cow/yr)	N value @ \$1.24/kg	P value @ ~\$1.85/kg P	Combined value 400-cow herd
Pasture-based (10–15% capture)	16–24	2–3	\$20–\$30/cow	\$4–\$6/cow	\$10,000– \$14,000/yr
Mixed / bail-fed (20–35% capture)	32–55	4–8	\$40–\$68/cow	\$7–\$14/cow	\$19,000– \$33,000/yr
Housed / freestall (70–90% capture)	111–142	15–20	\$138– \$176/cow	\$28–\$37/cow	\$66,000– \$85,000/yr

P price derived from DAP (~\$1,215/t ÷ 46% P content ≈ \$2.64/kg P equivalent; discounted to ~\$1.85/kg recoverable P to reflect lower bioavailability credit vs. commercial fertiliser). N price: 3-year domestic average urea price ~\$570/t ÷ 46% N = \$1.24/kg N (2023–25).

Figures exclude application costs and distribution losses.

Source: DA S&O May 2026 (MC-1726). (Source: Authur).

Key sources: Humphreys, J., Mihailescu, E. and Casey, I.A. (2020). 'Nutrient Intake, Excretion and Use Efficiency of Grazing Lactating Herds on Commercial Dairy Farms.' *Animals*, 10(4), 560. | Aarons, S.R., Gourley, C.J.P. and Powell, J.M. (2020). 'Nutrient Intake, Excretion and Use Efficiency of Grazing Lactating Herds on Commercial Dairy Farms.' *Animals*, 10(3), 390. | NC State Extension (2022). Dairy Manure as a Fertiliser Source | DA, Situation and Outlook, May 2026 (MC-1726) | DA, Effluent Applications Guidance.

Appendix A.2 – natural resource circular investment workings

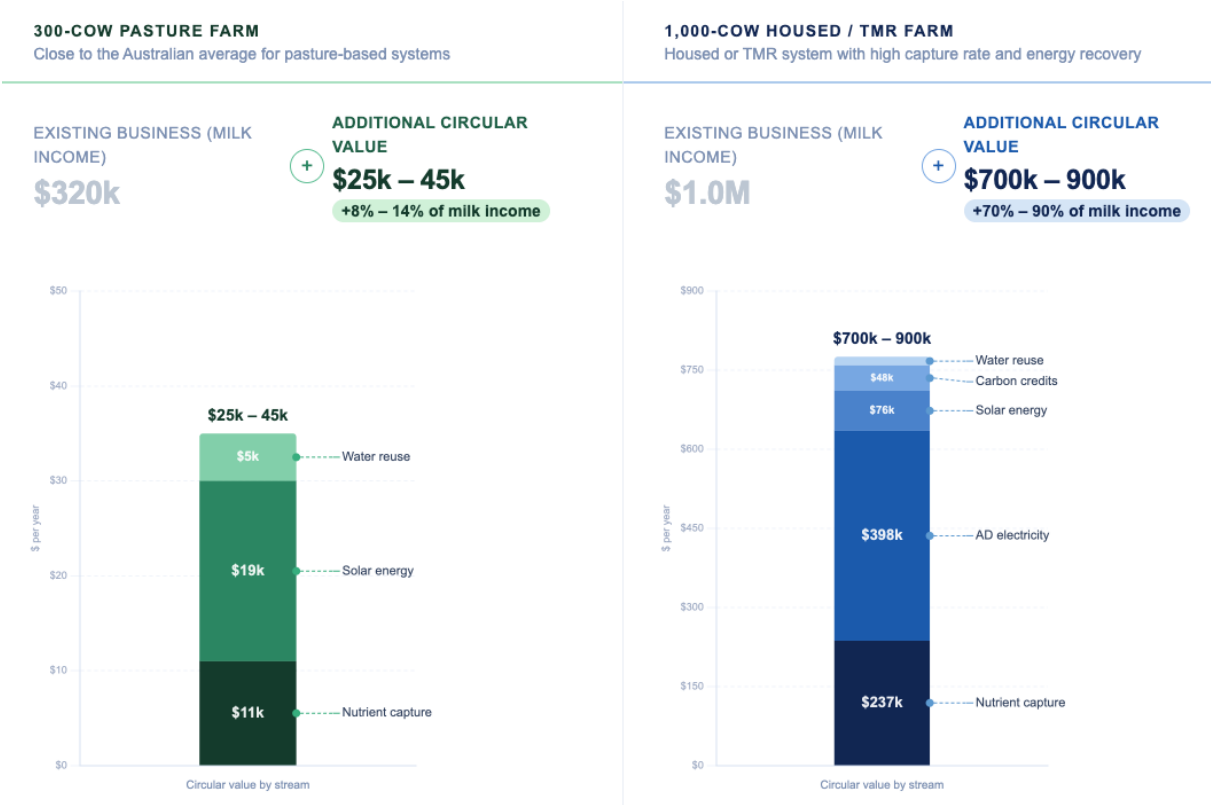


Figure A.2.1. The circular opportunity within existing resources. Estimated annual circular economy value by practice, compared to farm cash income — 300-cow pasture and 1,000-cow housed/TMR dairy farm, Australia (2025–26 prices). (Source: Author).

Working assumptions

Farm cash income: ABARES, Financial performance of dairy farms (2023–24); 300-cow scaled estimate; 1,000-cow proportional. Nutrient capture: 158 kg N/cow/yr (Humphreys et al., 2020); 10–15% capture rate pasture / 70–90% housed; urea ~\$1.24/kg N (3-year domestic average 2023–25, ~\$570/t ÷ 46% N; current May 2026 price of \$1,425/t excluded as war-driven spike); NPK value ~40–60% above N-only. Solar energy: 48 kWh/kL milk (Ag Energy Hub); \$0.35/kWh; 40–80% offset (Ellinbank SmartFarm; Mulheron Dairy VIC, 2024). AD electricity: scaled from ARENA 2021 (1,500-cow, 1.0–1.5 MW, \$500k–\$700k/yr). AD not viable for pasture systems. Carbon credits: \$40–\$56/cow net (Athian, 2024; DCCEE ACCU Animal Effluent Management method). Water reuse: \$252–\$294/ML (Murray–Darling Basin, 2025). All values are midpoints of estimated ranges; gross of capital repayment and operating costs.

Appendix A.2 – the commercial case for nutrient cycling

Table A.4 — Fertiliser Input Cost Pressure (April 2026)

Input	AUD/t (domestic, May 2026)	Change on prior year	Change on 5-yr average
Urea (N source, 46% N)	~\$1,425/t	+121%	+53%
DAP (N+P source)	~\$1,215/t	+25%	+4%

Source: Australian domestic market prices, May 2026. Urea ex-Geelong: Whistler Farm Supplies / Pacific Fertiliser (May 2026); DAP: DA, Situation and Outlook, May 2026 (MC-1726). World Bank Commodities Price Data (Pink Sheet), July 2026. (Source: Aurthur).

Current May 2026 urea price (~\$1,425/t, +121% year-on-year) reflects war-driven Middle East supply disruption. All calculations below use a 3-year domestic average urea price (~\$570/t, 2023–25), equivalent to ~AUD\$1.24/kg N (\$570/t ÷ 46% N content), to avoid overstating the long-run nutrient recovery opportunity.

↑ Urea prices have risen **121 per cent** in twelve months to May 2026, driven by Middle East conflict disrupting global supply chains. To normalise for this spike, calculations use a 3-year average urea price (~\$570/t, 2023–25). At **AUD\$1.24/kg N**, the nitrogen excreted by a single dairy cow annually represents **AUD\$196 of plant-available fertiliser** — most of which currently leaves Australian dairy farms as a cost rather than a return.

Table A.5 — Illustrative Fertiliser Replacement Value from Effluent Capture

Production system	N excreted/cow/yr	Est. capture rate	N captured/cow/yr	Value at \$1.24/kg N	400-cow herd	1,000-cow herd
Pasture-based (System 1–2)	~158 kg N	10–15%	16–24 kg N	\$20–\$30/cow/yr	\$8,000–\$12,000	\$20,000–\$30,000
Pasture + supplements (System 3–4, bail/PMR)	~158 kg N	20–35%	32–55 kg N	\$40–\$68/cow/yr	\$16,000–\$27,000	\$40,000–\$68,000
Housed / freestall TMR (System 5)	~158 kg N	70–90%	111–142 kg N	\$138–\$176/cow/yr	\$55,000–\$70,000	\$138,000–\$176,000

Source: N excretion — Humphreys et al. (2020), *Animals*, PMC7143236; N prices — DA S&O May 2026; capture rate estimates — DA's effluent guidelines and author's synthesis. (Source: Arthur)

Current May 2026 urea price (~\$1,425/t, +121% year-on-year) reflects war-driven Middle East supply disruption. All calculations below use a 3-year domestic average urea price (~\$570/t, 2023–25), equivalent to ~AUD\$1.24/kg N (\$570/t ÷ 46% N content), to avoid overstating the long-run nutrient recovery opportunity.

Table A.6 — Indicative Anaerobic Digestion Economics: 1,500-cow Freestall Operation, NSW

Capital & Revenue Estimates	
<i>Full system installed cost (with power generation)</i>	AUD\$1.2M–\$1.8M
<i>Approximate generation capacity</i>	1.0–1.5 MW
<i>Estimated annual electricity value (at \$0.28–0.35/kWh)</i>	\$500,000–\$700,000/yr
<i>Digestate nutrient replacement value (N only, ~90% capture)</i>	\$254,000–\$275,000/yr
Indicative combined annual benefit	\$755,000–\$975,000/yr
<i>Illustrative payback period</i>	1.5–2.5 years

Source: Author's synthesis from industry estimates; ARENA (2021), *Market Analysis of Opportunities in Australia for Anaerobic Digestion Deployment*. (Source: Arthur)

Note on system suitability: The Australian Renewable Energy Agency (ARENA, 2021) found AD "unlikely to be viable for pasture-based dairy systems." The economics presented above apply to housed or high-input systems where manure is collected at scale. This directly supports the report's argument that production system design — not technology alone — determines the viability of circular investments.

Data sources: DA, *Situation and Outlook*, May 2026 (MC-1726) | Humphreys, J., Mihailescu, E., Casey, I.A. (2020). "Nutrient Intake, Excretion and Use Efficiency of Grazing Lactating Herds on Commercial Dairy Farms." *Animals*, 10(4), 560. PMC7143236 | DA, *Effluent Applications guidance* | ARENA (2021), *Market Analysis of Opportunities in Australia for Anaerobic Digestion Deployment* | Author's calculations.