Australia’s National Science Agency

Business case for Australia's livestock gene bank

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Laercio R Porto-Neto, Sigrid A Lehnert, Katherine Wynn, Sonja Dominik, Antonio Reverter

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The authors also appreciate the feedback provided by stakeholders during the consultation interviews. Your willingness to contribute ideas and perspectives became an integral part of this report. Inevitably, not all of the presented positions could be incorporated into the report. Instead, the broad understanding of each theme was summarised.

Executive summary

The livestock gene bank discussed in this document refers to a living collection of cryopreserved genetic material such as sperm, embryos, and other biological materials that can be accessed to conserve and sustain animal genetic resources.

Worldwide, animal gene banks deliver on three main objectives:

1. To preserve the biodiversity of livestock species for the future.

2. Under an emergency preparedness banner, assist the protection of animal agriculture against environmental disasters and disease outbreaks, preserving genetic material that can be mobilised in a recovery phase.

3. To support Research & Development initiatives that benefit from stored genetic materials.

Livestock gene banks also help to future-proof the livestock industry, making it more productive and flexible to meet future consumer demands. Loss of genetic diversity can occur gradually through deliberate changes in production and consumer requirements. However, a large-scale loss of stock and genetic diversity can occur rapidly through natural disasters and health and biosecurity emergencies, impacting the Australian economy. In circumstances of either gradual or a rapid decline of genetic diversity, the gene bank could provide the genetic backing needed to assist in restoring the industry.

Despite the importance of livestock gene banks, Australia doesn't have one yet, and the Australian Government seeks to investigate the feasibility of establishing a national one. Four possible options for implementing a livestock gene bank were developed, and stakeholders (e.g., livestock breeders, breed societies, research institutes, and academia) were consulted to gather their feedback.

Most responders were supportive of a national livestock gene bank and thought it would make a valuable contribution to the industry. However, the perceived value differed with the scope and purpose of such a facility. The strongest support was for preserving rare or unique Australian breeds and for preserving herds bred from a multi-generation selection. The preservation of genetic material to trace genetic disorders across generations, restore diversity that might have been lost, and many applications within research/academics were also often valued.

The application of the gene bank in disaster recovery ranked lowly for most respondents. The perceived difficulties that limited the support included questions on how to decide which animals to cryopreserve, the potential need for large numbers of embryos and semen straws, the need to "update" the stock every so often, and uncertainties about the feasibility of its deployment. For the gene bank to also contribute to disaster recovery initiatives, more background work needs to be done to develop its concept further and clearly define a strategy. This will be better done in consultation with the industry.

The gene bank could go beyond a cryoconservation facility to leverage genetic material collected and stored by the industry. This hybrid option received the most support; it has a centralised gene bank and a voluntary registry of genetic resources available in the industry (breeding companies, farms, etc). This additional registry allows the bank managers better to understand the genetic resources available in the country. It expands the gene bank's engagement with the industry, directly strengthening its relationship with the reproductive biotechnology industry and livestock breeders.

There are some very well-established national gene banks worldwide. The American National Animal Germplasm Program is an internationally recognised example. It has a centralised management team and some species committees, including management, industry, and research representation. Australia would benefit greatly by interacting with that program to understand better the physical and computational infrastructure required and its governance.

The experience of existing gene banks and stakeholder feedback highlighted that a governance framework needs to be at the forefront of the implementation activities. Key requirements include clear definitions of the gene bank's objectives, who can access it, on which conditions, and who makes that decision, some of which might require legal advice. A clear definition of the objectives of the gene bank will drive decisions from the type of facility required to the type of samples, populations, volumes of material to be collected, and required governance structures. Most stakeholders believe the administration should be at the federal level, either the federal government or a federal institution, to facilitate continuity and avoid competing interests between states and territories. The government would also need to ensure long-term commitment and secure funding, which is required because the realised benefits of a livestock gene bank might come several years after the implementation.

The stakeholder interviews prioritised ruminants, cattle, and sheep, for cryopreservation. These livestock species have well-established reproductive biotechnologies with industry-based operational infrastructure. At a second stage of the implementation, the gene bank could expand to include other food-producing animals and other types of biological samples. To include some of these additional species, cryopreservation protocols will need to be developed. Recommended biological material to be stored is semen, DNA, and embryos where possible, and the sanitary status of the stored biological material needs to be accessed and adequately controlled. Sanitary protocols and controls will need to be put in place early in the implementation process.

An embedded R&D program within the national gene bank is strongly recommended in response to the stakeholder engagement and previous experience of international gene banks. The R&D program would drive innovation (e.g. developing cryoconservation protocols for less common species), and provide ongoing results that would assist in demonstrating the value of the gene bank. For example, all animals that are being cryopreserved should have a DNA profile using at least a DNA marker array, and some key individuals could also be whole-genome sequenced. This unique genomic resource could potentially be made public for Australian researchers supporting the translation of innovation to the industry, e.g. tracing genetic disorders, analysing population genetics, and assisting the national program for the genetic improvement of livestock.

Preamble

The concept of gene banks for livestock is not new, and many countries worldwide have already implemented some sort of a gene bank that assists their industry (animal agriculture and Research & Development initiatives). Currently, Australia does not have a national-level gene bank, but interest exists among stakeholders.

In late 2020, the Department of Agriculture, Water and the Environment (DAWE) organised a roundtable to discuss the concept of an Australian Livestock Gene Bank. During this roundtable, approximately 41 participants representing government, industry, and academia heard about international experiences implementing and using gene banks. The roundtable started a discussion on the use case scenarios and options for Australia to develop a livestock gene bank (or alternative).

Globally, livestock gene banks have been used to preserve genetic diversity, assist animal agriculture during the recovery phase of an environment or biological disaster (e.g. drought or a disease outbreak), and support continuous improvement in livestock productivity via research and development initiatives. In most successful cases, national-level management is put in place with long-term government support.

This report was commissioned as a result of the 2020 roundtable to investigate and assess if there is a business case for the government to invest in an Australian livestock gene bank to acquire germplasm and store it securely on behalf of the industry. The report includes an assessment of international experiences in managing gene banks, an overview of potential implementation options, a summary of stakeholder engagement/consultation on the different options, and an initial assessment of capability and infrastructure requirements.

Part I A business case for an Australian livestock gene bank

What is a gene bank?

The concept of an Australian livestock gene bank to be discussed in this options paper refers to the cryoconservation of livestock sperm, oocyte, embryos, and other tissues for conservation and sustainable use of animal genetic resources (FAO, 2012). It is referred to as *ex-situ* conservation as it relates to conservation efforts outside of living animals kept in the environment. Animal gene banks around the world are based on liquid nitrogen cryoconservation technology, where samples are stored at –196^{o}C. It has been shown that cattle semen stored from the beginnings of cryoconservation (50 years ago) is still viable and able to give rise to offspring when used in artificial insemination (Blackburn 2018). Cryoconservation technology is most developed in ruminants, with dairy cattle leading the way in a commercial application. Different livestock species have developed various cryoconservation technologies based on the reproductive biology of the species. Frozen embryos, oocytes, and primordial germ cells have been used to reconstitute live organisms and could be included in gene bank collections (FAO 2012). A gene bank may also store blood or other tissue samples and DNA with a view to potential future uses of this material.

To fulfill the definition of a gene bank, the resources are usually held by a host institution that is authorised and or recognised by a national authority to perform these tasks. One or more repositories could constitute a gene bank. The physical security of the samples and access to the collection are important aspects, emphasising a "bank" concept. Further, a gene bank needs to be underpinned by secure and accessible information systems that allow users to interrogate and search the collection and samples to be reliably retrieved and distributed (FAO 2012, Zomerdijk 2020).

The objectives of a gene bank for livestock

Gene banks around the world serve three key objectives:

1. **To preserve the biodiversity of livestock species for the future.**

The preservation of biodiversity is critical for animal agriculture. This has been the main motivation for establishing gene banks globally (see gene banks in action boxes below – UK and Netherlands gene banks). The FAO identified animal genetic diversity as a major factor in the capacity of agricultural production systems to maintain and increase productivity. Therefore, the preservation of global animal genetic resources for food and agriculture was identified as a major goal to pursue (FAO, 2007).

In Australia, the protection of breeds such as Droughtmaster, Murray Gray, and Australian Merino is of national interest. Additionally, unique breeds locally adapted to different environmental conditions are important reservoirs of genetic variation not present in other cattle populations. For example, "tropically adapted" cattle breeds with slick coats are more heat tolerant. The heat tolerance trait could be introgressed into other cattle breeds to improve their performance in subtropical or tropical regions of Australia. The term introgression refers to selecting and breeding animals to combine specific traits, in that case, the slick coat. For such an initiative to succeed, it is essential to be able to preserve genetic diversity, such as through a gene bank.

It would also be beneficial to preserve the genetic material of more common breeds, e.g., Angus, Brahman, and Santa Gertrudis cattle. These more common breeds are usually under stronger human selection than less common breeds, which could lead to loss of diversity, possibly due to strong selection towards one or few traits. This can become a problem by decreasing disease resistance through potential inbreeding practices. For example, in the USA, their gene bank assisted recovering a lost genetic diversity in the Holstein population by reintroducing some old sires into their population (see box – US gene bank). The preservation of genetic diversity is thus necessary for emblematic breeds, uniquely adapted populations, and common breeds of livestock.

Additionally, many properties across Australia carry livestock that represents multi-generational work in the genetic improvement of the herds. These selected lines of livestock should be protected to minimise the risk of losing all those long-term efforts. The existence and availability of a national gene bank could encourage more producers who own selected livestock lines to preserve and protect their hard work for future generations.

2. Under an emergency preparedness banner, assist the protection of animal agriculture against environmental disasters and disease outbreaks, preserving genetic material that can be mobilised in a recovery phase.

The role of livestock gene banks from a disaster preparedness perspective to protect animal agriculture is worth considering. Australia enjoys a privileged situation concerning animal disease status, being free of foot and mouth disease (FMD), bovine spongiform encephalitis (BSE), African swine fever (ASF) and other infectious agents capable of causing catastrophic losses to livestock industries. Despite Australia's robust biosecurity systems, the risk of an incursion of known or emerging disease is ever-present. An Australian gene bank designed with appropriate biosecurity protocols could help the industry recover quickly without the large impact on genetic progress and genetic diversity that would otherwise be inevitable during massive depopulation events.

In recent years, the Queensland floods resulted in the loss of hundreds of thousands of animals in a short period. An available gene bank could be mobilised during the recovery from such a situation (the herd expansion phase) by providing access to high-quality genetic material (semen and embryos) safely stored at the gene bank. On the other environmental extreme, Australia has also been severely affected by drought with devastating consequences. In this case, a gene bank could assist farmers in preparing for a herd reduction. If de-stocking is necessary due to ongoing drought, the gene bank could support farmers by providing the infrastructure needed to safeguard their genetics; semen and embryos could be collected from their most valuable animals beforehand for future use under favourable conditions. To assist during a recovery phase and preparedness, a gene bank needs a reasonable stock of genetic material that can be mobilised when needed and an infrastructure capable of receiving input that supports preparedness-related activities.

3. To support Research & Development initiatives that benefit from stored genetic materials.

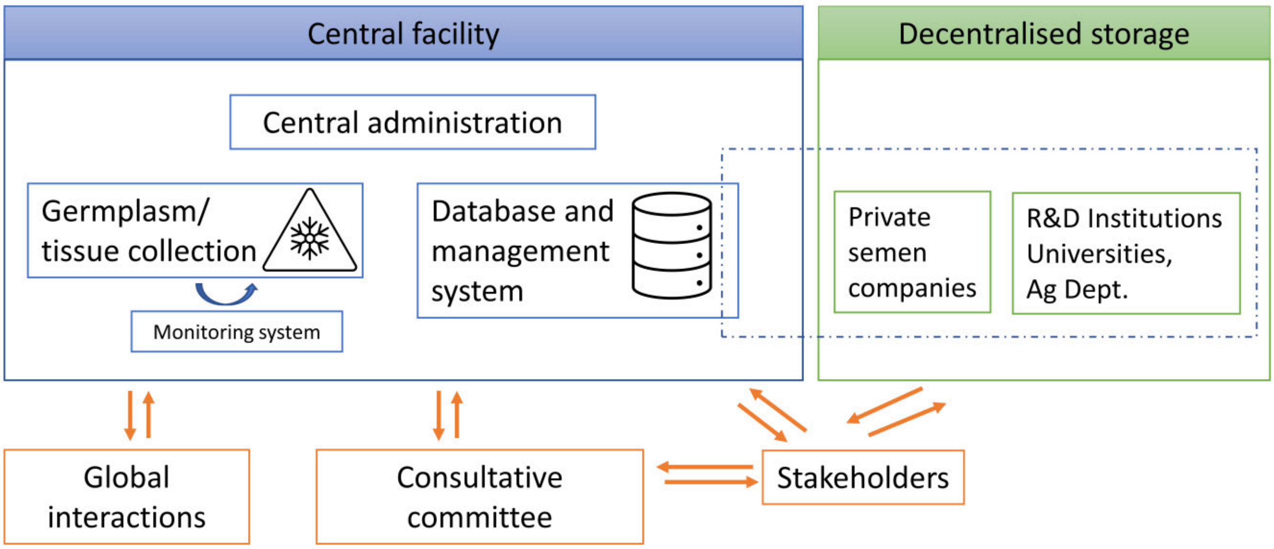
Finally, Research and Development initiatives that support animal production would also benefit from a gene bank. A publicly owned database would facilitate the engagement with the scientific community and industry providers independent of their commercial interests.

Scientific research that is enabled by an extensive gene bank collection includes population genetics (for example, testing whether a group of animals represents a distinct subpopulation), studies of genetic diversity (for instance, devising strategies to control inbreeding in commercially important breeds), the search for genomic signatures of tropical adaptation and genetic disease studies (for example the ability to trace newly identified genetic diseases or disease and parasite susceptibility across past generations). By cryopreserving germplasm, gene banks are also storing samples suitable for high-quality DNA extraction.

Large publicly owned gene banks also support other research and development (R&D) activities, such as innovations within cryobiology, which relate to developing strategies and methodologies to cryopreserve the genetic material of farmed animals without a known protocol (Blackburn 2018). Gene banks can also support R&D projects for reproductive biotechnologies.

Such research projects could, for example, assist breeding programs to minimise the detrimental effects of reduced diversity (or increased inbreeding), improve disease and parasite resistance, and improve productivity on-farm and beyond the farm gate. This could increase the productive output of Australia's agricultural industries, which is in line with the National Farmers Federation's target of increasing the farmgate value of Australian agriculture to $100 billion by 2030.

Key components of gene banks



Briefly speaking, gene banks around the world use several key components: a centralised facility, the gene bank *per se*, which consists of cryostorage equipment for long-term storage and preservation of the genetic material (e.g., liquid nitrogen tanks and ultra-cold freezers), a monitoring system, and a robust database for management of the genetic resources. Additional capability can be obtained by extending gene bank registries to include decentralised storage. Gene banks might be managed at the central administration level with additional input from industry-led consultative committees and stakeholders, serving the national interests with a global perspective.

The risks of not having an Australian livestock gene bank

The goal of livestock gene banks is to future-proof the industry by remaining productive and retaining the flexibility to meet future consumer demands. Loss of genetic diversity can occur gradually through deliberate changes in production, and consumer requirements, e.g., with a trend to low-fat diets, leaner livestock breeds become more profitable to producers. However, a large-scale loss of stock and genetic diversity can occur rapidly through natural disasters and health and biosecurity emergencies with major impacts on the Australian economy.

In the following, we attempt a description, including some financial estimates, of the risks posed to Australian livestock industries by natural and biosecurity disasters. The potential role a gene bank can play in mitigating these risks and speeding up disaster recovery is described in general terms. Our current knowledge of these systems does not allow us to estimate how much of the risk would be mitigated by deploying a national livestock gene bank during disaster recovery. Additional R&D would be required to model these scenarios.

Productivity loss from natural disasters

Australia has a long history of natural disasters in floods, droughts, cyclones, and bushfires. Natural disasters can cause substantial damage to rural communities, including extensive loss of livestock (Table 1).

For example, the Monsoon Trough Event in Northwest Queensland in February 2019 resulted in estimated livestock losses of 500,000 head (cattle and sheep) at the cost of $432 million. This livestock count is likely underestimated, as many of the losses were unbranded calves, which had not yet been mustered. The dollar value of these losses is also likely to be underestimated, as the per head cost of cattle was based on an average value of commercial cattle in this area. A number of the properties affected by the extreme weather event were bull breeding properties and cattle studs; the value of the lost livestock is likely to have been much higher than the average commercial sale or slaughter value. The estimate also does not include the impact on the multi-generations, long-term breeding programs that had been in existence at these properties.

Statistics on farm revenue do not completely capture the productivity impact of drought on livestock enterprises. On beef farms, drought has a smaller effect on revenue in the short term than on broadacre cropping because, in dry years, farmers sell stock to match their herd to the amount of feed available. Drought years further reduce herd sizes due to deaths and lower birth rates. This results in lower farm cash income over the longer term and risks losing genetic diversity (Hughes et al. 2019).

Table 1 Examples of estimated stock losses and associated lost gross output from natural disasters. 1967 to 2011 from Coll (2013), 2019 figures from Deloitte (2019).

Event	Estimated losses (number of heads)	Total gross output lost
1967 Black Tuesday fire, TAS	60,000 sheep, 1,350 cattle, 24,000 chickens, 600 pigs	$110 million
1982 Great Southern Storm Arkan, WA	100,000 sheep	$14 million
1983 Ash Wednesday fires, VIC and SA	340,000 sheep, 18,000 cattle	$65 million
1990 Great flood QLD, NSW, VIC	300,000 sheep, 11,000 cattle	$52.5 million
1990/1991 Hay and Murrumbidgee fires, NSW	176,000 sheep, 200 cattle	$24.5 million
2005 Katanning rains, WA	91,000 sheep	$13 million
2005 Victoria bushfire	63,243 sheep, 40 cattle	$6 million
2007 Esperance area storm, WA	43,255 sheep, 40 cattle	$6 million
2009 Victoria fire	22,707 sheep, 1,844 dairy cows, 12,968 beef cattle, 111 pigs, 3,231 chickens	$19 million
2010/2011 Victoria floods	11,321 sheep, 392 dairy cows, 97 beef cattle, 364 pigs, 330,184 chickens	$5.5 million
2019 North Queensland floods	457,000 head of cattle (excluding unbranded calves), 43,000 sheep	$432 million

Biosecurity risks for Australian livestock industries

Invasive pests and diseases can threaten Australian livestock populations by causing direct deaths and as a result of destruction and disposal of unaffected animals as part of disease control strategies. The cost of a hypothetical multi-state foot and mouth disease outbreak in Australia, for example, has been estimated to amount to revenue losses of between $49.3 billion and $51.8 billion (in present value terms) over ten years (Buetre et al. 2013). The loss to the horse industry as a consequence of the 2007 Equine influenza outbreak was estimated to have been $370 million based on compensation payments from Australian governments as a proxy for real costs incurred by the horse industry and horse community. Biosecurity has a constant risk in our globalised society.

The use of the gene bank in response to a biosecurity incident aligns with its use in response to a natural disaster – during the recovery phase, it can be accessed to assist animal production in becoming viable again, allowing herd/flock expansion with animals of good genetic background. The preparedness that a gene bank provides for a natural disaster is extendable to biosecurity incidents.

Risk of loss of genetic diversity to the Australian livestock industries

Widespread loss of livestock from pests and disease or natural disasters has long-term consequences for the Australian livestock industries. In addition to the immediate economic cost from stock loss, the recovery period and restocking require substantial resources, the latter often not captured in the cost. Financial losses encountered during the recovery period are caused by the losses of genetically elite animals and the loss of genetic diversity in a population.

Genetic diversity is the engine room of genetic improvement and is a key requirement for sustainable livestock industries that can respond to changes in production environments or markets. In the first instance, a bottleneck of elite genetics and lost genetic diversity will substantially affect the stud sector. Still, these impacts will persist for a long time after a disastrous event and continue to affect the commercial sector through a lack of genetically superior stock, inhibiting quick return to previous production levels. Genetic improvement has been achieved in all major breeds, e.g., Australian Angus returns in commercial herds have been improved by over $75 per cow mated per year over the last 20 years (Rickards 2012). When this increase in value is multiplied by the 11.7 million cows and heifers mated per annum over this 20-year period (MLA 2020), it represents a significant potential financial loss from the large-scale destruction of genetically valuable animals.

Risk of losing livestock genetic resources unique to Australia

Australia has adapted several exotic livestock breeds to the Australian climate. The Merino sheep breed is one such example, and the use of Brahman genetics for beef production in northern Australia is another. Extensive science-based genetic improvement programs for exotic animals extend to farmed aquatic species (Atlantic salmon). The local adaptation of these breeds to the Australian climate and the creation of stable composite breeds have created unique Australian livestock breeds that underpin the productivity of this important industry sector.

In addition, iconic Australian species such as barramundi and prawns are transitioning from farming wild-caught broodstock to developing structured breeding programs with genetic improvement objectives such as feed efficiency and disease resistance. The development of these genetic improvement programs would significantly benefit from the research made possible through a national collection of well-categorised genetic samples.

A gene bank of unique Australian genetic livestock resources should be part of Australia's disaster preparedness.

Gene banks in action – international examples

The US gene bank – National Animal Germplasm Program (NAGP)

The US National Animal Germplasm Program (NAGP) was initiated by the US Department of Agriculture in 1990, in response to US Congress legislation calling upon the department to establish a National Genetic Resources Program.

The NAGP has since grown into one of the world's largest gene banks and currently stores germplasm from 41 livestock species. The USDA NAGP component of the larger Center for Agricultural Resources Research is currently receiving non-competitive, long-term government funding to manage its collection. The USDA NAGP focused on commercially relevant species and was initiated by donations from the commercial sector. In turn, these donations have been made possible by a strong legal framework governing ownership, management, and access to gene bank samples. For example, large breeding companies often request a 10-year embargo on their donations, during which they cannot be made publicly available.

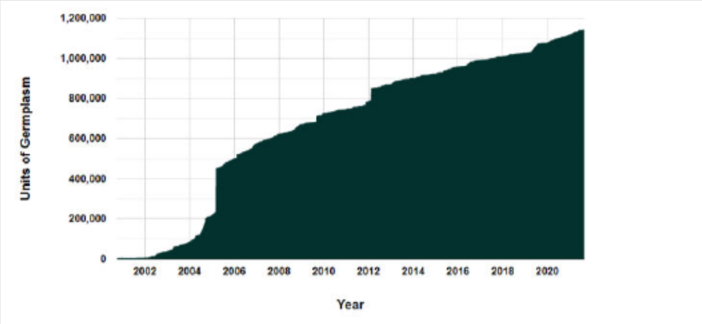


Figure 1: Growth of the USDA NGAP collection in units of germplasm over time. The collection currently stands at 1.14 million units. Source: NGAP website August 2021.

While the initial motivation for the establishment of the US gene bank had been to conserve genetic diversity, as insurance against the loss of rare breeds, it has since found more diverse and unforeseen uses (Blackburn 2018). NAGP now receives a large number of germplasm requests for genetic studies based on the DNA content of the samples. Stakeholder requests to access germplasm are assessed by the appropriate NAGP "species committee", which determines the release of the requested material.

For example, a breed association requested access to a progenitor bull that had been used historically and had semen stored in the gene bank. One semen straw was used to test whether the bull was a carrier for a lethal mutation that was causing an issue in the industry decades later. Because the bull was found not to carry the mutation, 30,000 animals related to him did not have to be tested. Blackburn (2018) estimates that this saved breeders and the association US $2 million.

The use of NAGP germplasm to reintroduce genetic diversity into existing breeds is heavily promoted and supported. The industry benefits from these reintroductions are difficult to quantify but are likely to be substantial. For example, the US collection of dairy bull germplasm is so substantial that in 2014, it was found to contain a greater number of Y chromosome lineages than were represented in the industry at the time. Additional Y chromosomes could be reintroduced to this globally important breed of cattle using the gene bank and safeguarding genetic diversity for future generations (Blackburn 2018).

The UK gene bank - Rare Breeds Survival Trust (RBST)

The Rare Breeds Survival Trust (RBST) is a company limited by guarantee registered in England as a Charity (Charity number: 269442). Their key objective is to safeguard the UK's rare and native breeds of farm livestock, namely the Watchlist, against diminishing numbers and potential threats posed by disease outbreaks. A key part of RBST's work involves collecting genetic material in the form of semen and embryos.

The need to expand the Gene Bank became urgent in the wake of the 2001 Foot and Mouth disease crisis in the UK and was supported by the Prince of Wales. Passionately supportive of the work carried out by RBST, His Royal Highness has said: "Our rare breed livestock are part of our heritage and contain a genetic diversity that we desperately need to maintain in the face of an uncertain future."

The current objectives of the RBST Gene Bank are four-fold: (1) For security to safeguard breeds into the future; (2) To ensure future genetic diversity; (3) For current conservation breeding to produce new breeding lines; and (4) To store genetics that may otherwise be lost.

The majority of the Gene Bank is made up of semen from males from cattle, equine, sheep, goat, and pig breeds. RBST also collects embryos from cattle, goats, and sheep. With 67 breeds featuring in 2019, the Watchlist has been compiled using a new methodology for calculating breed status. The new approach compares effective population size with measures of inbreeding to give a more accurate reflection of true conservation status.

RBST has a network of regional volunteer support groups throughout the UK. These groups are an integral and important part of the organisation helping in several different ways, including (1) Running a social calendar for members and volunteers, often including meetings, talks, and farm walks; (2) Attending country, food, and farming events to promote RBST; (3) Offering advice to new breeders; (4) Supporting the regional network of show and sales of rare and native breeds; (5) Fundraising; (6) Recruiting new members; and (7) Giving talks to other groups.

Publicly available financial data for RBST shows substantial reserves available (over £3million).

Y/E	Filed on	Income £k	Spending £k	Surplus/ Deficit	Fundraising Cost £k	Total Funds £k	Unrestricted Funds £k	Mths Rsrvs	Staff	Volun-teers
31/12/19	02/10/2020	£527	£716	-£188	£213	£3,328	£3,189	2	9	500
31/12/18	18/11/2019	£577	£958	-£381	£313	£3,169	£3,070	1	10	500
31/12/17	12/10/2018	£816	£687	£128	£201	£3,810	£3,720	1	10	500

Source: https://givingisgreat.org/charity-factsheet/?regNo=269442

One of the prime objectives of the charity is to ensure the preservation of breeds. Therefore, a Gene Bank is maintained to ensure the characteristics of old and current breeds are conserved. This Gene Bank is treated as a heritage asset, which is irreplaceable. The Trustees have therefore designated £2million to maintain and develop the Gene Bank for the next generation.

The Netherlands gene bank

The Center for Genetic Resources in the Netherlands (CGN), funded by the Dutch government, is situated at Wageningen University and Research. Its website states that the gene bank for animal resources comprises a collection of over 300,000 doses of sperm in liquid nitrogen and also stores embryos, oocytes, and DNA. The gene bank consists of material from 10 different species and represents almost 8,500 animals. The collection stretches back to 1966.

The goals of the CGN, as stated on its website, are:

> *Securing the genetic diversity of rare breeds and more common breeds.*
>
> *Using genetic material to support rare breed breeding programs.*
>
> *Providing insurance for calamities such as the loss of breeds due to animal disease.*
>
> *Making material available for research and genetic characterization.*

Its strategy for adding to the collection is described in a 2019 news (weblink below) item as "At regular intervals, in close collaboration with cattle, pig, and horse breeding industry and breed societies, CGN is collecting "snapshots" of many and diverse breeding animals, capturing the genetic diversity within breeding populations or breeding lines. In some cases, already frozen genetic material can be acquired from breeders or semen collection centers. Moreover, for other species and rare breeds in general, CGN takes initiatives to collect and cryopreserve semen of any interesting or representative individual ("targeted expansions")."

The CGN distribution policy is governed by their Quality Management System (QMS), certified under ISO 9001-2015. The QMS "allows gene bank managers to identify the needs of users and other stakeholders, formalize the procedures to satisfy these needs, analyze the risks, and take actions for continual improvement" (Zomerdijk et al. 2020).

The CGN, with more than half a million samples, is the largest member of the European Genebank Network for Animal Genetic Resources (EUGENA). This network of 9 gene banks (11 countries) was formed with European Union funding and has resulted in a portal that provides access to the collective resources of the member gene banks.

By sharing information and data, EUGENA members are supported in achieving their objectives, which are broadly in line with FAO's Global Plan of Action for Animal Genetic Resources, and achieving overall quality improvement of gene banks in Europe.

Weblinks:

The Center for Genetic Resources in the Netherlands (CGN). https://www.wur.nl/en/Research-Results/Statutory-research-tasks/Centre-for-Genetic-Resources-the-Netherlands-1.htm

2019 CGN news. https://www.wur.nl/en/Research-Results/Statutory-research-tasks/Centre-for-Genetic-Resources-the-Netherlands-1/Show-CGN-UK/Considerable-expansion-of-the-animal-gene-bank-collection-in-2018.htm

European Genebank Network for Animal Genetic Resources (EUGENA). https://www.eugena-erfp.net/en/genebank-detail?gbank=21

Options for an Australian livestock gene bank

Four possible options for implementing a gene bank for livestock are presented. These options vary in upfront investment and running costs. More importantly, they differ in terms of the service they can deliver to the agriculture sector and, in particular, the livestock industry. In the following section, the four options will be briefly discussed, highlighting some pros and cons. Option 1 is, in fact, the counterfactual "no gene bank" option; the industry continues as it is without a gene bank. Under Options 2-4, different gene bank structures with varying complexity and delivery mechanisms are discussed. This section is followed by a graph representation summarising the various options and their estimated associated costs (pages 17 and 19, respectively).

Options 2-4 would all involve collecting and preserving livestock species samples.

Species contemplated

In the first stage, the gene bank would support the livestock species of cattle and sheep. These species represent a combined annual value exceeding $23 billion and have well-developed protocols for cryopreservation of genetic material (Table 2). A whole industry sector supports these activities (e.g., technicians that collect and assess the quality of semen samples and the associated industry to process them into cryopreserved semen straws).

Once established, the gene bank could grow to include other species relevant to food production, e.g., goats, pigs, chickens, and aquatic species salmon and barramundi.

For the full usefulness of gene banks, the species under consideration must have well-developed methodologies and laboratory protocols for preserving genetic material in semen, eggs, embryos, or primordial germ cells.

Table 2 summarises some species and their stages of development in cryobiology. An eventual gene bank would also collect and store genetic material other than gametes, e.g., skin biopsies. These could be used for several genetic analyses and, as a long shot, for cloning processes.

Table 2. Commonly farmed animal species in Australia and progress towards biobanking

Species	Indicative annual farm gate value of industry#	Cryopreservation methods exist	Breeding programs exist	Existing holdings of material	Risk mitigation*
Cattle (dairy, beef)	Beef $13.1 billion Dairy $4.3 billion	Yes (sperm, embryos)	Domestic and global	Yes, large	B, ND, GD, U
Sheep (wool, meat)	Meat $3.3 billion Wool $3 billion	Yes (sperm, embryos)	Domestic and global	Yes, large	B, ND, GD, U
Barramundi	$0.09 billion	Need development	Domestic (beginning)	No	B, ND, U
Salmon	$0.9 billion	Yes (sperm), need further development	Domestic	Some	B, ND, U
Pigs	$1.4 billion	Yes (sperm, embryos)	Domestic	Yes	B, U
Goats (meat, milk)	Meat $0.15 billion Milk $0.02 billion	Yes (sperm, embryos)	Mostly global	Some	B, U
Chicken	Meat $2.8 billion Eggs $0.8 billion	Yes (sperm, germ cells)	Global	No	B
Prawns	$0.1 billion	Germ cells, need further development	Yes	No	B, ND, U

* B = biosecurity, ND = natural disaster, GD = loss of genetic diversity, U = unique Australian genetic resource.
# Figures from ABARES (2017) and ABARES (2020).

Option 1. No gene bank. Continue with the status quo

It is possible to envisage a role for the government in continuing with "business as usual", where the private sector continues to hold and manage livestock genetic resources. This role may incur very low additional costs and consist of raising awareness of existing private Artificial Breeding Centres, breed societies, and other private sector entities that could play in preparing for and recovering from disasters. There is limited scope for these entities to assume a role in managing genetic diversity.

The current AUSVETPLAN Enterprise Manual for Artificial Breeding Centres (Animal Health Australia, 1999) already describes a role for artificial breeding centres during an emergency animal disease response. It is unclear how realistic it would be to expand the scope of AUSVETPLAN to include the documentation and monitoring of genetic diversity and the genetic value of their collections to assist in disaster recovery. It is also unclear whether the R&D required to tackle the development of cryopreservation technology for additional farmed species (for example, aquaculture) would be undertaken by the private sector or made broadly available.

Pros: Minimal investment.

Cons: It doesn't assist in delivering any objective of a livestock gene bank.

Option 2. Centralised registry (government managed and voluntary) and decentralised storage (private)

This option would involve a voluntary register that captures a suite of data on livestock genetic resources within Australia. It would be based on existing storage infrastructure and collections (private industry and research sector) that are voluntarily declared and captured in the national registry. Artificial reproductive technologies have been a part of cattle and sheep breeding for many decades. Artificial insemination, pioneered by the global dairy industry, relies on the secure collection, storage, and transport of semen on a commercial scale. Several private Artificial Breeding Centres provide services in this space (Appendix 1) and could be interested in listing their stocks in the national registry.

Some companies listed (Appendix 1) have technical expertise in collecting, processing, and storing semen and embryos. These services are usually accessed by stud breeders, breed societies, and R&D organisations. The main intent for accessing such a service provider is to preserve valuable germplasm, making it available when required for personal use or sale. Additionally, it is worth mentioning that some multinational companies work in this space (semen and embryo). Many commercial artificial breeding centres have privately-owned cattle and sheep semen stored.

Some publicly funded R&D providers (e.g., universities and government departments) have collections of genetic materials (DNA, tissues, semen) used for research projects. Some are DNA collections linked to specific genetic disorders accumulated over many years, defining a valuable genetic resource. It is unlikely that these R&D organisations will pass on their collection to a centralised repository; on the other hand, they are likely to contribute with data describing their collection to be included in a centralised repository.

A limited amount of government funding could result in a central database, financing for genomic characterisation of existing resources, or annual data collation. R&D funding could be provided for projects to document and monitor livestock genetics over time, allowing the industry to address risks as they emerge within the inventory. This strategy could help inform and speed up disaster recovery arrangements by helping facilitate the rapid deployment of known genetic resources to match disaster recovery needs.

Given the voluntary nature of the registry, it is unclear whether this option offers sufficient incentive to the private sector participants to provide and share data to the central register and keep the registry updated. The respective roles and responsibilities of private and research sector partners would need to be defined.

Pros: Leverage current industry cryostorage infrastructure and genetic material.

Cons: All of the cryostorage facilities and the genetic material are privately owned, limiting quality control, security, and access to the stored material. Keeping the database updated and relevant may be challenging due to the need to have industry collaborators providing relevant information.

Option 3. Fully centralised gene bank

A physical gene bank could build on existing capacity within the private and the research sectors to collect and store livestock genetic material. Government support in the form of secure long-term funding, governance, and a legal framework would ensure that this resource could be effectively deployed in disaster recovery, management of genetic diversity, adaptation to changes in the market or environmental conditions, and research.

An Australian livestock gene bank could operate as a centralised entity (registry and storage), as in the USA. It could consist of a purpose-built or make use of an existing facility.

A government-backed livestock gene bank would need to partner very effectively with the private sector to build sufficient scale. Once operational, a physical gene bank will provide the national scale and the universal access required during disaster recovery, assisting the industry in recovering from an environmental or animal disease emergency. This is particularly relevant to industries that are built on unique germplasm originating or developed within Australia over several generations.

Several strategies could be implemented to ensure diverse breeds' representation and the scale of material stored. These strategies need to be fully developed, but as an example, the gene bank could partner with relevant industry partners in semen collection, processing, and storage. Half of the processed semen straws could become the property of the gene bank, and the breeder would retain ownership over the other half. Such a strategy would increase the gene bank stock numbers and help with drought preparedness in pastoral industries by enabling more aggressive de-stocking. Adding such a strategy to Australia's disaster management may result in better environmental outcomes and more effective recovery following drought.

As breeding females will probably be a limiting factor in the herd and flock rebuilding following a disaster, the livestock gene bank could invest in specialised collections to address this situation, for example, embryo collection and cryopreservation or the use of sexed semen technologies. For livestock, most of the technologies for preserving genetic material are already developed.

On the other hand, the protocols for cryopreservation of gametes are not well-developed for other agriculturally relevant species (e.g. chicken, salmon, or barramundi). The existence of a gene bank could stimulate and eventually support R&D activities toward this goal. Beyond livestock, other animal production industries face similar challenges regarding the potential loss of genetic diversity, risks to environmental factors (drought, floods), and disease outbreaks. It is also worth noting that an available gene bank and advanced genomic technologies represent a powerful combination for scientific discovery. This combination would allow genetic disorders to be tracked at a national scale and the discovery of genetic variants impacting the adaptation of some livestock to specific environments and potentially reinventing animal breeding programs towards more resilient animals that are better matched to their environment.

Pros: A fully controlled gene bank allows the development of strategies to address its key objectives, including a quick response during disaster recovery.

Cons: Relatively higher initial investment and running costs when compared to the previous options. A centralised gene bank may not be able to leverage current cryostorage based on industry and research organisation collections.

Option 4. Hybrid option – centralised gene bank (registry and storage), with additional decentralised storage (private)

Option 4 for the national gene bank represents an extension of option 3 to include the centralised registry suggested under option 2. This implementation would create a centralised gene bank and a robust registry to leverage privately managed/stored genetic material (semen and embryos) and R&D collections.

This option would allow a national-level disaster response on two fronts: via a voluntary register of private sector genetic resources available to be mobilised during disaster recovery, plus a central repository that would be built up over time with genetic diversity objectives as its main priority. By operating in this way, the large volumes of privately-owned genetic material could be accessed in a more coordinated fashion for disaster recovery or even to increase the capability of private enterprises to market their collections during non-disaster periods.

Longer-term objectives to manage the genetic diversity of livestock breeds and conserve unique Australian genetic resources can be implemented at the level of the physical gene bank. The physical gene bank may also be able to expand the focus from cattle and sheep out to other species and novel biotechnology solutions.

The added R&D opportunities and government support, evident by the investment in a national level cryostorage, may incentivise industry participation in the gene bank network more than option 3.

Pros: The fully controlled gene bank combined with the registry of decentralised genetic material across Australia, material that doesn't have to be moved or change ownership, would allow a speedy response to a natural disaster while supporting the other objectives of a gene bank (maintenance of the genetic diversity and R&D activities).

Cons: Equivalent to option 3. Relatively higher initial investment and running costs when compared to the previous options 1 and 2.

Summary of options for the Australian livestock gene bank

	OPTIONS			
	1. No gene bank	2. Centralised registry, decentralised storage	3. Fully centralised gene bank (registry and storage)	4. Hybrid – centralised gene bank, with decentralised storage
Preparedness				
Drought preparedness and recovery	limited	limited	yes	yes
Animal disease emergency response	limited	limited	yes	yes
Conservation				
Rare breeds conservation	yes	yes	yes	yes
Management of genetic diversity	no	limited	yes	yes
Ability to track genetic change over time	no	limited	yes	yes
R&D activities				
Genomic and biotech R&D for productivity	no	no	yes	yes
Cryobiology R&D for additional species	no	no	yes	yes
Genomic analyses to track genetic disorders	no	limited	yes	yes
Leverage existing semen/DNA storage				
Can benefit from existing semen/embryo storages	no	yes	limited	yes
Can benefit from existing DNA archives	no	yes	limited	yes
Engagement with industry				
Semen companies	no	yes	limited	yes
Breeders (with incentives to collect material)	limited	limited	yes	yes
Safety storage				
Assurance of quality and safety	no	no	yes	yes
Full control, allow quick intervention	no	no	yes	yes
Associated cost				
Management software	no	yes	yes	yes
Dedicated facility	no	no	yes	yes
Labour*	short term consult.	2 staff	4 staff	5 staff
Estimated initial investment (cryogenic equipment only) ($'000)	$50	$150	$1,010	$1,010
Estimated running cost p.a. (labour, maintenance, building, operating costs) ($'000)**	0	$310 – $430	$1,260 – $1,530	$1,400 – $1,720

* Labour. It is expected that this level of staffing will be necessary for a few years during the implementation phase. After this initial period, the number of employees could potentially be reduced.

** See detailed information on the table below.

Communication and stakeholder engagement activities for gene bank options 3 and 4

It is suggested that along with the development of the infrastructure for housing and managing the gene bank, a series of implementation activities should be conducted. For the success of the gene bank, strong engagement with stakeholders will be needed. A communication strategy could include media activities, workshops, field days, and small grants subsidising breeders' contributions to building up the gene bank.

In addition, a research & innovation strategy may be built around the gene bank initiative. A topic that will require research investment relates to developing strategies for the optimal use of the gene bank when facing a natural disaster or disease outbreak. This could be done by modelling different use scenarios to define the most effective way to deploy the gene bank as part of disaster preparedness or recovery.

Another topic of interest for the gene bank relates to the development of methodologies to cryopreserve (gene bank) additional species of commercial interest that don't have an established protocol. The gene bank could allocate funds and make a project call in the form of research grants within the theme of cryobiology. Research projects within this line would broaden the scope of the gene bank, leveraging on the established infrastructure.

Additional input (R&D, communication) would be required to develop this program of activities. The estimated cost for these activities has not been included in the figures in Table 3 below.

Estimated costs (infrastructure and maintenance) for gene bank options 3 and 4

The cost estimate for a gene bank listed in Table 3 covers upfront investments and running costs. These were defined in consultation with equipment providers. It is worth noting that these estimates are only indicative. For instance, the expenses related to the physical facility (renting existing or purpose-built) will vary depending on the location, administering organisation, site availability, and building choice. Similarly, the choice of database and management system could greatly impact the overall cost. Here it is suggested to use systems already developed for other gene banks (e.g., NAGP from the US), adapting the software to Australia's specific needs. If a decision were made to develop a customised database solution instead, this would mean additional upfront investment.

The duplication of equipment allows safety backup and an additional level of biosecurity. The pieces of equipment listed are two liquid nitrogen storage tanks (-190oC, Biostore III) and two ultra-cold freezers (-80oC, Stirling Ultra). Combining these two types of equipment represents the ideal starting infrastructure where semen, embryos, oocytes are stored at -196oC, while DNA, blood, skin, and other tissues are stored at -80oC.

The running costs included the maintenance requirements of the equipment, the facility (mentioned above as highly variable), labour expenses, and operating costs for running and expanding the gene bank. The number of staff dedicated to the gene bank during the implementation phase will likely be higher than once all procedures are developed. Nonetheless, the labour component is a major cost item within the gene bank.

Table 3. Cost estimate for gene bank options 3 and 4 (excluding communication and stakeholder engagement activities).

Equipment	Stirling Ultra SU780XLE	Biostore III 1800 – single tank
Description	Single energy-efficient electrical -80°C freezer without automation	Single nitrogen vapour tank with box-level automation
Temperature	-80°C	-190°C
Life expectancy	12 year	20 years
Samples types	DNA, blood, and other tissues	Semen, embryos (could also use for DNA and tissues)
Number of samples	Up to 60,000 2ml tubes	Up to 250,000 straws
Upfront costs		
Equipment	$80,000 (40,000 x 2)	$700,000 ($350,000 x2)
Additional gas backup (nitrogen injector with UPS; nitrogen plumbed to unit)	$50,000	-
Monitoring system (e.g. temperature)	$10,000	$20,000
Database development, managing system development (1 FTE one year)	$150,000	
Upfront investment cost TOTAL	**$1,010,000**	
Running costs		
Equipment maintenance p.a.	$2,000	$30,000
Energy or liquid nitrogen cost p.a.	$2,000	$30,000
Equipment maintenance Total	**$64,000**	
Leased cryostorage facility (e.g., building, security)	$30,000 p.a. (renting)* $35,000 (purpose built)**	
New state of the art facility including having the potential to collect samples on site	To be determined in a later part of the gene bank project	
Operating cost (new samples collection, processing, DNA typing and storage)	$500,000	
Labour (salaries) p.a.	$670,000 - $935,000 (option 3) $810,000 - $1,125,000 (option 4)	
Running cost p.a. TOTAL	**$1,260,000 – 1,530,000 (option 3)** **$1,400,000 – 1,720,000 (option 4)**	

* Costs associated with the gene bank physical facility are highly variable across Australia and building options (e.g., renting space or building its own). Estimated costs for renting space on an existing laboratory (30sqm) with access to existing liquid nitrogen infrastructure and office (10sqm) areas are reported.
**25m^2 single brick building with engaged piers, tin gable roof, roller door, and man door (building only, excluding land purchase, security, or liquid nitrogen infrastructure). It is foreseen that such a building would necessarily be in an existing high-security facility.

Part II Stakeholder engagement

Insights, comments, and observations from these interviews

Preamble

At the first stage of the project, the CSIRO project team developed four options on how an Australian Livestock Gene Bank could be operationalised. In the second stage, the concepts are presented to stakeholders to gather feedback on the different options and comments on the establishment of a national gene bank more generally.

Ethics clearance was obtained for the conduct of stakeholder interviews from the CSIRO Social and Interdisciplinary Science Human Research Ethics Committee (CSSHREC) (application: "Business Case for Australia's Livestock Gene Bank", reference 129/21). The project team defined a process for conducting the interviews that included the provision of information prior to the meeting in the form of a "Research Participant Information Sheet" (Appendix 1). All participants consented to the use of the content of their interview to be used and reported as part of the project.

The list of potential stakeholders to interview included the participants in the Department's 2020 Roundtable discussions that consented to be contacted by CSIRO. The project team contacted additional stakeholders in industry, State government and artificial breeding services provision. To date, 20 interviews have been conducted (Table 1).

Table 1. Summary of interviews conducted until now.

Affiliation type	Number of interviews completed
University	4
RDC and related institutions	5
Breed Societies	4
Sheep breeder	1
Pastoral Company	1
Industry reproduction services (AI)	4
State government Agriculture department	1
Total	20

General support for a gene bank - perceived value proposition

Most respondents see that an Australian Livestock Gene Bank would fill an unmet need and may make valuable contributions to the industry. The value that respondents associated with a National Gene Bank differed with the perceived scope and purpose of such a facility. The strongest support was for preserving rare or uniquely Australian genetic resources represented by tropically adapted beef cattle and Merino and selected commercial genetics. As expected, strong support was encountered from respondents who are involved with rare livestock breeds, as they have been lobbying for government support for their conservation efforts for a while. However, respondents from other backgrounds also stated that they would value the opportunity to preserve some genetics to track deleterious mutations, to restore genes (or genetic variations) that may otherwise be lost or for research and development. Universities identified a National Gene Bank as a valuable resource primarily for teaching and education but also for research and development. The purpose of a National Gene Bank for disaster recovery ranked lowly for most respondents mainly because of the perceived difficulty of deciding what genetics to store and the logistics of storage of embryos in addition to semen and subsequent regeneration *in vivo* following a disaster. Some respondents expressed reservations about whether an investment of this type would be the best use of government funds. Respondents from industries that are dominated by large global corporations (for example, dairy, and pork) confirmed that these organisations already hold large stocks of semen and in the case of the dairy industry, have access to offshore genetic resources. Representatives of these industries stated that they had adopted risk mitigation strategies "in-house" to guard against the impacts of biosecurity or climate-related disasters.

In our conversations with interview partners who had not been part of the initial Roundtable discussions, the potential benefits of an Australian Livestock Gene Bank became clearer to them during the interview. This illustrated that the rollout of the concept will require a clear plan for broad engagement with industry and other stakeholders to collect additional feedback, raise awareness, and encourage participation.

Purpose and potential benefits of a gene bank

Our interview partners confirmed the potential benefits of a Gene Bank listed in our first discussion paper and identified additional aspects.

For example, the highly globally connected nature of dairy breeding, while viewed as solid "insurance" against disasters occurring in Australia, may also expose the industry to risk. The routine importation of semen from overseas could be shut down very suddenly if a disease emergency arose in an overseas location. If a gene bank store substantial Australian holdings of imported semen that the industry relies upon, this could be deployed to overcome the lack of fresh imports.

Many respondents agreed with the monitoring and maintenance of genetic diversity as an important purpose of the Australian Livestock Gene Bank. There was general agreement that the initiative would present a significant opportunity for productivity research. Genomics of cattle and sheep, but also cryobiology, and reproductive technologies were mentioned. Two of the university academics interviewed could see the potential for the Gene Bank to be a valuable resource for teaching and research if it was co-located with a leading veterinary school.

A number of respondents expressed reservations about the Gene Bank's deployment in disaster recovery. Some of the comments related to the fact that female animals (recipients) were usually the limiting factor in disaster recovery, that it would be unlikely the Gene Bank collection would be able to acquire and hold large enough volumes of the most up-to-date genetic material, and that importation of material from overseas was more likely to aid in disaster recovery. Respondents also discussed the difficulty in deciding which genetics to store unless objective information, such as breeding values, is available.

During the interviews, it became clear that most respondents had not considered the opportunity of a National Gene Bank for disaster recovery to date. Respondents' opinions evolved during the conversation to the point that they could start seeing the value of having an additional tool for disaster recovery available, even if it was not going to deliver a complete solution.

The preferred option for the Gene Bank operating model

A brief outline of the four options for the Gene Bank was provided in our pre-interview information pack:

1. *No gene bank. Continue with the status quo*
2. *Centralised registry (government-managed) and decentralised storage (private)*
3. *Fully centralised gene bank (registry and storage)*
4. *Hybrid option – centralised gene bank (registry and storage), with additional decentralised storage (private)*

Our respondents told us that options 1 and 2 would be difficult to implement in practice and unlikely to create value for the industry. Reasons cited for this were:

- The variety of proprietary database tools used by different companies.
- The workload involved for small companies in providing regular stock updates to the Gene Bank.
- The commercial nature of the information and the commercial value of the holdings.
- Given that participation would be voluntary, the benefit to the participating companies needs to be clearer.

The overwhelming feedback was that for the Australian Livestock gene bank to be a credible initiative, it would need to include a centralised, secure cryostorage facility, option 3 or 4. Industry participants who are currently hosting significant cryostorage facilities (two reproductive technologies providers and one large dairy genetics provider) were interviewed. Their feedback was that an Australian Livestock Gene Bank would not threaten their business model. They would be open to participating in the initiative along the lines of option 4, which was the preferred option.

Options for building the Gene Bank collection

Respondents envisaged several options to build a body of cryopreserved stock for a National Gene Bank. These included:

- the Gene Bank would pay for the collection of semen and processing, then share straws with the bull owner.

- breeding companies to donate semen or embryos.
- owners of semen or embryo might donate excess stock or superseded genetic resources.
- engagement with existing gene banks that already have collections (e.g. breed societies and universities collections).
- linking with historic archives.
- public/private partnership to provide fee-for-service centralised storage facility to the Australian artificial breeding industry.

Respondents elaborated on the motivations that might drive contributions of stock. These included:

- subsidies for semen donation.
- the opportunity to distribute the risk associated with small number of suppliers for commercial artificial breeding services ("corporate disaster").
- breeding companies might want to safeguard their commercial interests.
- contribution to an initiative for national benefit.
- enable R&D.
- might offer cost-savings to artificial breeding companies.
- best practice promoted by breed societies.

Location & governance for gene bank options 3 and 4

Our respondents unanimously identified the federal government or a "federal institution" as the preferred entity to be managing this initiative. Universities were seen as likely to disinvest in response to budgetary pressures or the departure of a particular "champion" of the facility. Having said that, two of the university academics interviewed have already lobbied their respective universities and were expressing their interest in a partnership with the federal government, along the lines of hosting the facility at a regional campus.

Several respondents told us that they would envisage one central, secure facility, but just as many voiced their support for a "hub and spoke" model where Gene Bank satellites might be located in the major agricultural regions of Australia. The increased security that such an approach would offer was pointed out by practitioners who have had first-hand experience of technical challenges with cryostorage.

Several of the respondents mentioned the need to develop robust protocols to govern the security and access to the material. It was pointed out that this aspect of the collection's security would be as important as the physical security of the facility. Donations from the industry would only be forthcoming if those protocols and a legal framework were established. The expectation is that decisions about access to material, whether for disaster recovery, R&D or commercial reasons, would need to be made or ratified by an independent committee (independent of Gene Bank management). This committee could include scientists, industry representatives and RDC.

Key challenges

The key challenges for the development of a Gene Bank mentioned by stakeholders were:

- The majority of stakeholders interviewed identified secure, long-term funding for the gene bank as a critical success factor. Some of the respondents quoted the Australian Pastures Gene Bank's example as a similar initiative that looks about to fail because of the challenge of obtaining year-on-year funding commitments from its contributors.
- A clear statement of purpose is needed to guide the remainder of the strategy (acquisitions, species focus, location(s), governance).
- Database tools to underpin acquisition strategy, efficient deployment of resources, sample and data security and R&D – these may not be available off-the-shelf.
- For the gene bank to remain relevant, especially for disaster recovery, the stock would need to be renewed regularly to keep pace with genetic progress in the industry.
- The process to select the right genetic resources to be stored with only a proportion of the industry with objective information. Selections would also be influenced by the purpose of storage (e.g. disaster recovery vs rare genes).

Offers of support

In line with the broad expression of support for the initiative, a number of the stakeholders volunteered their support. This feedback indicates that the federal government may receive valuable in-kind support from stakeholders if it chooses to fund the establishment of the gene bank. Specifically, stakeholders offered:

- Input and feedback on governance and other establishment issues.
- Participation in the advisory committee.
- Partnership with the gene bank by hosting the facility (e.g. as part of a university campus).
- Donation of semen samples on discard list (on condition that robust access protocols are in place).
- Access to DNA sample collections and genotypic and phenotypic databases (on condition that robust access protocols are in place).
- Communication with their members/clients to elicit participation in the gene bank.

Part III Recommendations

Develop a clear statement of purpose

Gene banks around the world serve three key objectives:

1. To preserve the biodiversity of livestock species for the future.
2. To support Research & Development initiatives that benefit from stored genetic materials.
3. Under an emergency preparedness banner, assist the protection of animal agriculture against environmental disasters and disease outbreaks, preserving genetic material that can be mobilised in a recovery phase.

The first two listed above were the original objectives of the first conceptualised gene banks worldwide. Its use in emergency preparedness is comparatively new but is of growing interest to governments and industry.

A clear definition of the objectives of the gene bank and expected outcomes is needed because logistics, choices for sample storage and governance are specific to meet each of the objectives. The requirements for objectives 1 and 2 are more aligned than objective 3. It is possible to contemplate all three key objectives if planning considers the differences from the onset.

For instance, by storing 50 semen straws from 100 bulls, a cattle breed can be cryopreserved. This would allow "rescuing" an endangered population and support R&D activities. On the other hand, for emergency preparedness, thousands of samples of specific breeds may be required, and samples may need to prioritised on genetic value.

The second point of difference associated with the purpose of the gene bank relates to the flow of genetic material and the frequency of updated samples. For the storage of rare genetics, it would not be required to update genetic material, however, for emergency preparedness, genetic material needs to be a reflection of the current population to maintain relevance for a productive herd.

The purpose of the gene bank will govern many aspects, from the strategy for implementation, governance, and funding requirements.

A hybrid operating model is recommended

Four possible options for implementing a gene bank for livestock were presented (Part I).

1. *No gene bank. Continue with status quo*
2. *Centralised registry (government managed) and decentralised storage (private)*
3. *Fully centralised gene bank (registry and storage)*
4. *Hybrid option – centralised gene bank (registry and storage), with additional decentralised storage*

The fourth option, the Hybrid option, is recommended as it had the most support among stakeholders. This suggested implementation includes a dedicated facility with cryopreservation capability and an additional voluntary computer-based registry of biological resources (semen and embryos) available in privately owned cryo tanks. The idea of the registry is to gather information on available material that could potentially be accessed if needed (e.g. to bring genetic diversity to a population, research application, or quick access to material in response to an emergency).

Establish ongoing funding support

The funding base for such an initiative was of concern among the many interviewed stakeholders. A gene bank is a long-term investment, similar to insurance, where the benefits are realised after several years. This is more relevant for its potential contribution to the population rescue of extinction, maintenance of genetic diversity, and emergency support, whereas the benefits of scientific contributions could be instantaneous.

It needs to be highlighted that although realised benefit might occur at a later point in time, the initial investment in safeguarding genetic material can be compared to investments in agricultural biosecurity that safeguard Australia from threats that are not yet present; both of them need ongoing support.

It became clear from the interviews with potential stakeholders that donations to establish the gene bank will not be forthcoming unless the long-term funding of the initiative is assured.

A gene bank is a long-term initiative. It requires ongoing support and long-term and secure funding from its conception to its routine operation.

Establish a strong governance framework

The responsibility for the overall oversight of the gene bank operation needs further investigation. The appropriate governance structure is dependent on the objective and associated coordination. For example, recommendations on how decisions on acquisitions, storage and distribution of genetic samples should be made, or the legal requirements and obligations of the various parties cannot be made before deciding on the primary objective. Input from the legal team might be required in this process to inform specific aspects.

The Federal Government or a federal institution was perceived (by stakeholders) to be better positioned to manage this initiative than State departments or Universities.

The US provides an excellent example of an existing well organised centralised gene bank, that might provide a useful template for Australia regarding processes, implementation, and running of their centralised gene bank. The United States Department of Agriculture manages the "National Animal Germplasm Program", an exemplar, internationally recognised animal gene bank. This twenty-year-old gene bank includes materials on 44 species in a large, centralised facility. The good relationship between the US and Australia would facilitate this interaction.

Considering the above example, Australia may consider a centralised management team and a series of "species committees" that would guide actions towards the material to be collected and evaluate requests to access the gene bank. Depending on set-up options, committees should include industry and scientific/academic representatives. During the interviews, several stakeholders expressed their willingness to contribute to the committee activities that would be required.

A framework would need to be established to determine which samples are stored and for how long to underpin the objectives of a gene bank. This includes the type of material and the health standards. On the other hand, there also needs to be a clear governed process regarding the distribution of genetic material, who can access collections and under which conditions.

As in the "Funding" recommendation above, industry feedback indicated that a strong governance framework would be essential to ensure that industry donations will be forthcoming. The establishment of this framework would need to be budgeted for in the establishment costs of the gene bank.

Decide on a location

The specific location for the centralised facility and management team is not defined. It needs to be secure (access to the building and material) and has demonstrated a long-term commitment to this initiative. A reliable transport network for cryogenic tanks will also be essential.

Three possibilities could be envisaged since no firm views regarding a specific location were expressed by stakeholders. These could be further developed depending on the funding opportunity that exists and the preferred type of enterprise the Federal Government would like to put in place:

- **Purpose-built facility**. At a location to be defined, a secured facility is built. This would include cryostorage spaces, laboratory, and office areas.
- **Join forces with CSIRO**. Currently, CSIRO manages the National Research Collections Australia. Part of these National Collections is the National- Wildlife, Fish, Insect collections and the National Herbarium. These diverse collections demonstrate previous experience in managing large volumes of samples and preserving biological material. Additionally, these are held in secure facilities that could possibly also accommodate a livestock gene bank. No discussion about this possibility was initiated due to a potential conflict of interest.
- **Join forces with one (or two universities)**. During the stakeholder consultation, two Universities demonstrated interest in hosting a gene bank facility in their campi. They talked about the potential scientific contributions and mentioned that they would be open to discussion towards some joint venture with the federal government. These opportunities could be further explored and developed. Not all universities with livestock or genetic research programs were interviewed during the stakeholder engagement, so possibly other universities would also be interested in this discussion.

Prioritise species and materials

In the first stage, the focus should be on cattle and sheep. With particular attention to beef cattle and wool sheep, since Australia has some unique genetic resources.

The materials to be stored are semen, embryos, and extracted DNA.

Cattle and sheep have very well-developed cryopreservation and international sanitary protocols for semen and embryos. There is also a whole supporting industry using these types of genetic material, which will facilitate the industry's adoption of the gene bank and its growth.

In addition to the biological samples, every animal that becomes part of the gene bank (mainly via semen samples), should have its DNA profiled. At a minimum this profiling should utilise a single nucleotide polymorphism array (SNP array), while whole-genome sequencing should be performed on a proportion of samples to provide additional data. This information would be complemented with any other phenotypic information known about the animal (farm, breed, productive traits, etc). While the DNA profiling of all animals going into the gene bank represents a significant cost, it is important to note that the generated dataset will cut costs in the future, allow better monitoring of the animal in the gene bank, and expedite R&D initiatives. Most genetic studies will require, at minimum, DNA profiling of the animals; if this is already done, the project could go straight into the genetic analyses.

Combining the production data and DNA profiles would strongly drive the relevance of the gene bank. It would facilitate scientific outcomes and possibly better inform the industry about its diversity and genetic merit. DNA profiles and production data allow for the calculation of genomically estimated breeding values. These could be used to gauge the relevance of the animals in the gene bank, comparing them to the broad industry. Additionally, it could guide the need to add additional or replace existing stored genetic samples with those from animals of higher genetic merit. This point is relevant for more common breeds and not so much for rare and endangered populations, where every animal is important.

It is foreseen that the sanitary status of historical material, e.g. semen already collected and stored that is made available to the gene bank, might not meet international or export biosecurity requirements. It is worth noting that a lot of cattle and sheep semen processed in Australia is destined for "domestic use only". These collections represent a large proportion of the national inventory and should not be prevented from becoming part of the gene bank. It is possible to put sanitary controls for the semen being submitted to the gene bank. For instance, separate cryo tanks could be maintained for "export grade" material (semen and embryos), and for "domestic use". The "domestic use" semen could then be tested for several transmissible diseases before long-term storage.

In a second stage, once the gene bank is established and functional for cattle and sheep, other livestock and aquaculture species should be considered to expand the benefits. The first additions could include domestic species like pig, chicken, barramundi, salmon, and native production species like the emu. There are no protocols for the cryopreservation of genetic material for some of these species. Developing these protocols is an obvious activity for an embedded R&D program.

Embed an R&D program at the core of the gene bank

As mentioned before, most of the time, part of the realised benefit of implementing a gene bank occurs several years after the initial investment. If no clear gains are observed, it might become harder to keep the momentum (and the investment). On the other hand, the scientific relevance of a livestock gene bank is constant and can assist in providing ongoing support and demonstration of its relevance regularly.

An embedded R&D program would, for instance, support the development of cryobiology protocols to preserve gametes of other species than cattle and sheep – possibly increasing the relevance in an Australian context.

Within cattle and sheep collections R&D activities could relate to analyses of population genetics, tracing deleterious genetic mutations across generations, and supporting activities towards the multibreed calculation of genetic merit. Many facets could be explored; with a centralised investment, the data generated could potentially be shared among research institutions for scientific use.

To properly implement and embed an R&D program, funds should be specifically allocated from the annual operational budget. The gene bank management team (and species committees) could define priorities each year and run a competitive process of research grants to fill known knowledge gaps.

Plan for growing the gene bank (in terms of sample numbers)

To maintain and increase its relevance over time, the gene bank needs to grow in terms of the number of populations and samples that are stored. There should be a target on the number of new bulls and rams that are brought in to the collection every year. The constant collection would provide a sample of each generation of livestock and strengthen the genetic links between the gene bank and industry.

Several approaches could be used to grow the gene bank, and likely more than one mode for obtaining samples will be used.

Contracting artificial breeding centres. The gene bank could contract artificial breeding centres to collect semen specifically for the bank in a targeted intervention. One potential way to gain access to bulls or rams could be to pay for the collection and processing of semen and share the processed straws with the bull/ram owner (a form of a subsidised collection).

Donation of "new" material. Often during a semen collection, many more semen straws are produced than the producer need. Small volumes (n~20) of surplus semen straws would be made available by producers aiming to contribute to the greater good of improving livestock productivity (feedback on stakeholder consultation, breed societies, and producers).

Donations of "old" material. Large volumes of semen stored in farms and artificial breeding centres could be donated to the gene bank. Some of these are older material, but others are simply not relevant to that particular breeder anymore. Having them available to the gene bank would be useful in either case.

Receiving donations of semen is a great form to engage with stakeholders, but producers need a clear statement of who can access it and on what terms.

Producers will engage and donate. However, these donations are likely to represent small volumes of semen straws from many animals. This is great for developing a diverse gene bank, which is a key aim but will not necessarily deliver for emergency preparedness goals, where large volumes of semen are necessary. This is why the more costly methods of obtaining material (contracting a breeding centre) will also need to be considered.

Part IV Additional points to consider for the implementation

International guidelines and international experiences

Internationally, the cryopreservation of food-producing animal genetic resources is not a new practice. FAO has excellent guidelines and processes for implementing animal gene banks and their utilisation. Australia has a lot to gain from exploring proven protocols and interacting with well-established gene banks.

Key FAO references:

FAO (2012) Cryoconservation of animal genetic resources. FAO Animal Production and Health Guidelines No. 12. Rome. https://www.fao.org/3/i3017e/i3017e00.pdf

Commission on genetic resources for food and agriculture. Intergovernmental technical working group on animal genetic resources for food and agriculture. (2021) Genomic characterization of animal genetic resources for food and agriculture. 19-21 May 2021. https://www.fao.org/3/nf387en/nf387en.pdf

Commission on genetic resource for food and agriculture (2021) Draft practical guide on innovation in cryoconservation of animal genetic resources. 27 September – 1 October 2021. https://www.fao.org/3/ng882en/ng882en.pdf

Communication activities

In general, most of the stakeholders contacted were favourable to the initiative during the consultations. They highlighted however that if this project were to go ahead, more information would be needed before they decide to contribute. The key aspects of concern related to who would be able to access the material, who would decide, and on which conditions a request could be made. These are fair points that will need further development with stakeholder groups and possibly legal advice.

Additional stakeholder consultation. An expanded group of stakeholders should be contacted. These interactions could come in different forms such as Town Hall events, online questionaries, individual or group interviews, in-person, and phone.

Publicising the gene bank and stakeholder engagement. The relevance of a gene bank could be measured by its representation of the genetic diversity of the whole industry. Industry stakeholders need to see the value, engage and contribute genetic material. This will be facilitated by targeted publicity and engagement of producers with the gene bank operations.

Operating Principles

The number of samples needed

The FAO guidelines provide some indicative numbers on the number of animals to be sampled to reconstitute a breed via the utilisation of semen or embryos (FAO, 2012). https://www.fao.org/3/i3017e/i3017e00.pdf , p63-81).

As a brief example, the number of semen straws needed to reconstruct a ruminant breed could be estimated as follows: with 100 initial females and a pregnancy rate of 0.5 using a backcrossing approach, at least 12 straws from 50 bulls would be needed to obtain 25 males and 25 females that were at least 94% genetically “pure” to the reconstituted breed. To add an extra cushion, 20 straws from 50 unrelated bulls would allow further certainty that a reconstitution of the breed was technically feasible. These are achievable numbers for many cattle populations.

As mentioned earlier in this report, the concept of using the gene bank in emergency preparedness needs further development. The volume of genetic material (semen and embryos) available for emergency purposes needs to be further explored. This will include discussions on the type of material to be collected, breeds, definition on access, and other relevant topics.

Remaining relevant over time

Here a clear separation exists between the use for small, rare breeds and those more commonly bred livestock. For small breeds, the strategy to cryopreserve enough genetic material to reconstitute that population should be targeted. After this initial collection, new sires could be added to the collection every other generation.

The gene bank could take a different approach for more commonly bred livestock. For instance, it could enlist stud breeders to provide enough material to reconstitute a population every five generations – every year, the gene bank would collect material from a different property, returning to the first property every five years. Additionally, these stud breeders would provide small amounts (n~10) of each sire they collect semen from so that genetic mutations could potentially be traced over time across many generations. This approach (or variations of it) would allow the gene bank to remain genetically relevant over time.

Access to the gene bank

Livestock producers were agreeable to contributing genetic material to the greater good (the national livestock gene bank), but they were less agreeable to giving access to their genetic material to their competitors. There will need to be clear definitions regarding when genetic material can be accessed and by whom as well as who can grant access. Stakeholder consultation and legal advice should be explored while discussions with other gene bank managers internationally will be useful as they may have had to deal with similar problems already.

Database

The recommended option for implementation of the livestock gene bank includes a centralised facility and a registry of decentralised (industry-based) stored genetic material. There is existing database software capable of managing samples and genomic data designed explicitly for gene banks, e.g. A-GRIN from the US, which is the backbone of their National Animal Germplasm Program.

As recently as 2019, Brazil started using A-GRIN in collaboration with the US (Blackburn et al., 2019). It is known that the US is open to collaboration in this area, so it makes sense to at least explore this possibility as a starting point.

The recommendation for the implementation also includes a national registry of the genetic material stored by industry. This component will probably need to be developed to allow integration with the main database; and could be part of a scoping study during the first year, followed by a public tender for its commission.

Committees

It is envisaged that several committees will need to be in place during the development, implementation, and operation of the livestock gene bank. Some will persist only during the initial stages, while others will be ongoing.

Importantly, all these committees should have a dedicated staff (possibly shared across different committees), and direct input from stakeholders (industry organisations, producers, and research/academic institutions).

A non-comprehensive list of the committees would include:

Implementation Stage

A committee or task force could be mobilised to develop the legal framework and other documentation (e.g., general governance, material transfer agreements, "rules of engagement" – who can access the facilities resources and when, etc).

An additional committee or advisory group would guide the development of database solutions that are fit for purpose, being able to integrate industry collections, the gene bank proper, and their interactions. This group could, for instance, investigate potential access to systems already in place in other gene banks around the world and, if appropriate, further tailor these systems for Australia's needs.

These committees would be made up of representatives from industry, academia and government and appointed following a call for expressions of interest and selection process. Several representatives from industry bodies, government and academia expressed their willingness to contribute in-kind towards this committee work and an ongoing management committee.

Ongoing Management

Steering committee. This committee would coordinate all gene bank activities and would be made up of representatives from industry, academia and government and be appointed following a call for expressions of interest and a selection process.

Species committee. In the initial stages, the gene bank could have a single species committee that would discuss the matters related to cattle and sheep. With the addition of other species, more committees could be created so subject matter expertise was maintained. Initially this committee will evaluate requests for accessing the gene bank and assist in defining populations (or animals) to be cryopreserved. Similarly to the other committees, the membership of this committee would include representatives from the industry, government and academia.

R&D committee. This committee would manage R&D resources that ideally would be set aside for the purpose on an ongoing basis. Running a competitive process, for instance, it could coordinate R&D projects that make use of the data collected by the gene bank (e.g. to estimate breeding values and monitor the “quality” of cryopreserved animals or trace genetic disorders), or make investments for the development of technology (e.g. cryopreservation methods) that would allow new species to become part of the gene bank. The R&D committee would also include representative from the industry, government, and academia, with stronger focus on scientific advancement.

Communication and stakeholder engagement. It will be essential to have ongoing engagement with stakeholders, and for that, a comprehensive communication strategy should be developed, deployed, and evaluated frequently.

Staffing

The initial estimate for implementing a gene bank suggests an allocation of five staff with varying qualifications and base salaries. The first few years of operation might require more staff while all documentation, procedures, and operations are being developed; this number could potentially be reduced after these initial years.

The staffing requirements could be part of a scoping study run during the first year of the projects implementation, aiming to be operational in the second year.

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Appendix A - Artificial breeding centers and semen companies servicing Australia

(Non-comprehensive list)

Company	Location	Species	Services	Website
ABS Global Australia	Bundoora, VIC	bovine	semen sales, import	https://www.absglobal.com/au/company/
Agri-Gene Australia	Wangaratta, VIC	bovine	semen collection, storage, import, export	https://www.agrigene.com.au/
Alta Genetics	Tullamarine, VIC	bovine	semen	https://australia.altagenetics.com
Apiam Genetic Services	Bendigo, VIC; also TAS	bovine, ovine, caprine, porcine	semen and embryos	https://www.apiam.com.au/genetic-services/
Australian Premier Genetics	Coonabarabran, NSW	bovine	Semen and embryo collection, import, export, storage	https://www.apiam.com.au/genetic-services/
Bass Valley Embryo Services	Loch, VIC	bovine	embryo collection, storage	https://bves.com.au/
Beef Breeding Services	Parkhurst, QLD	bovine	semen collection, storage, embryo import export, storage	https://beefbreeding.com.au/
Brecon Breeders	Keith, SA	ovine	semen and embryo collection, storage, import, export	https://www.breconbreeders.com.au
Breeder Genetics		bovine	semen sales and distribution, database of beef sires	https://breedergenetics.com.au/
Breedtech	Jingalup, WA	ovine	semen and embryo collection, storage, import, export	https://breedtech.com.au/
Castlereagh Artificial Breeders	Castlereagh, NSW	bovine	semen collection and storage	https://www.castlereaghab.com.au/
Ced Wise	Glen Aplin, QLD	bovine	semen and embryo collection, storage, import, export	https://cedwiseabservices.com.au/
Gene Movers	Maddingley, VIC	bovine	Semen and embryo import, export, storage, distribution	https://www.genemovers.com.au/
Genetics Australia	Bacchus Marsh, VIC	bovine (mostly dairy)	semen collection, storage, sales, dispatch	https://genaust.com.au/
Genstock	Kojonup, WA; Jerilderie, NSW	ovine	semen collection and freezing, AI, ET	http://genstock.com.au/

Global Reproduction Solutions	Goorambat, VIC	bovine	embryo collection transfer, splitting, export	https://www.grsembryos.com.au/
Holbrook Breeders Australia	Holbrook, NSW	bovine	semen and embryo collection, freezing, ET, export	https://holbrookbreeders.com.au/
Holbrook Vet Centre	Holbrook, NSW	bovine and ovine	embryo collection, transfer etc	https://www.holbrookvetcentre.com.au
Inventia Genetic Technologies	Brisbane and Toowoomba, QLD	bovine	IVF, embryo tech	https://www.inventiagenetictechnologies.com.au/
Just Genes	Brisbane, QLD	all species	semen storage, import	https://www.justgenes.com.au
Livestock Breeding Services	Jerilderie and Yass, NSW	ovine	semen, embryo services	http://www.livestockbreedingservices.com.au
North East Genetics	Huon, Vic; Bega, NSW	bovine	beef and dairy AI	https://northeastgenetics.com.au/
Northern Artificial Breeders	Scone, NSW	bovine	semen collection and storage, AI, semen and embryo storage and dispatch	http://northernab.com.au/
Rocky Repro	Alton Downs, QLD	bovine	semen and embryo collection, storage, import, export	https://rockyrepro.com.au/
Semex	VIC	bovine	semen	http://semex.com.au/
ST Genetics	Albury, NSW	bovine	semen collection, sexed semen, import, export, storage	https://stgenetics.com.au/
Westbreed	Northam, WA	ovine	semen and embryo collection, storage, import, export	http://www.westbreed.com.au/

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Dr Laercio Porto-Neto
+61 7 3214 2443
laercio.portoneto@csiro.au

Dr Sigrid Lehnert
+61 7 3214 2445
sigrid.lehnert@csiro.au

Dr Antonio Reverter
+61 7 3214 2392
toni.reverter-gomez@csiro.au

Dr Sonja Dominik
+61 2 6776 1376
sonja.dominik@csiro.au