Sustainable Farm Animal Breeding and Reproduction

A Vision for 2025

Farm Animal Breeding and Reproduction in Europe – <u>Characteristics</u>
- Farm animal breeding includes all animal species bred for a wide range of purposes.
- For breeding, animals meeting defined criteria are selected from animal populations.
- Farm animal species have been selected for desirable traits since they were first domesticated.
- Efficient reproductive techniques, such as artificial insemination, allow genetic improvement to be rapidly disseminated from the top of the breeding pyramid to benefit all producers and society as a whole.
- Animal breeding and reproduction are most effective when incorporated into herd and population management strategies.
- Balanced breeding requires a long-term sustainable vision developed jointly by breeders, scientists, and society.
- The added value of investments in genetics is cumulative.
- Breeding is knowledge intensive.
- An international farmers' organisation has established guidelines for data collection, farm management, and genetic evaluation to assist farmers and farmers' organisations.
- Breeding is society sensitive because it drives changes in the genetic makeup of animals and the use of new technologies (e.g. genomics, computing sciences).
- Genomics opens innovative prospects for sustainable animal production.
- A Code of Good Practice for Farm Animal Breeding and Reproduction Organisations is in place to encourage transparency and a dialogue of breeders with society.
- Breeding supports the health, feed efficiency, and welfare of farm animals as well as adequate management of animals and the environment.

FABRE Technology Platform
Sustainable Farm Animal Breeding and Reproduction Technology Platform

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Foreword

The European landscape is characterised by a range of diverse farming systems. These relate not only to varied geographical environments, but also to different social and cultural environments for farming and food production. This diversity is unique to Europe and underlines the importance of European agriculture.

Increased demand for a plentiful supply of cheap food that also maintains a diverse and sustainable supply represents a challenge for traditional agricultural systems. In the field of livestock farming, demands for high welfare production systems and the maintenance of landscapes in the face of outbreaks, or the fear of outbreaks, of animal disease and of increasing international competition, threaten the European model of agriculture.

These are also challenges for European livestock breeding, which has long been recognised as a world leading industry. Challenges, however, also present opportunities for European farm animal breeding and the livestock industry as a whole: an opportunity because new technologies offer the possibility of accommodating the divergent demands of European consumers.

New technologies, however, can stir strong emotions. It is important for society to discuss technologies that are controversial in nature in the light of its own demands and ethical standards. Not all new technologies, however, need to be controversial, and the exploitation of information on the genomes of animals, as for humans, represents an opportunity to revolutionise science.

The Farm Animal Breeding and Reproduction European Technology Platform, FABRE TP, brings together a wide range of interested parties to produce a vision of how livestock breeding might develop in the next 20 years, and constitutes the first step in achieving that vision.
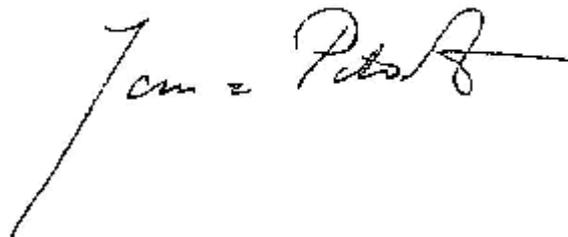
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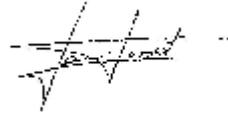
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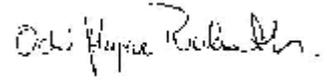
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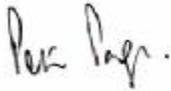
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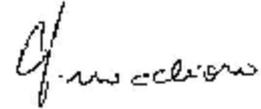
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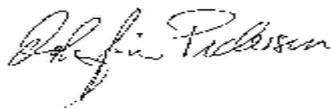
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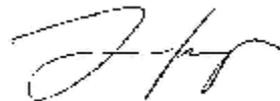
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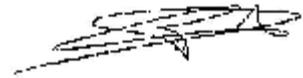
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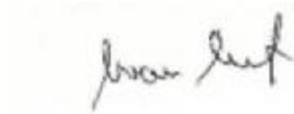
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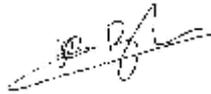
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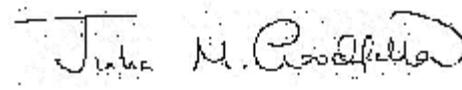
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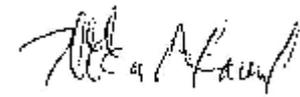
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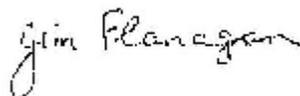
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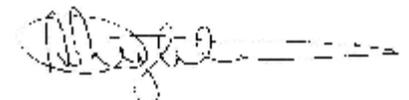
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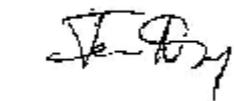
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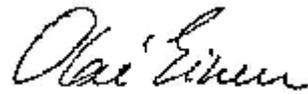
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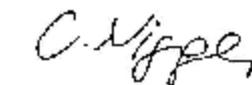
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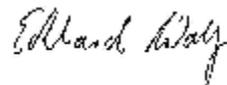
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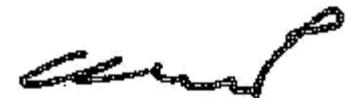
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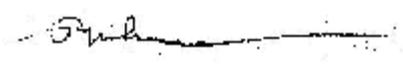
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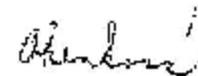
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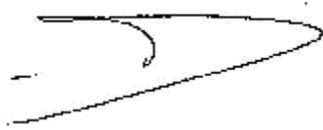
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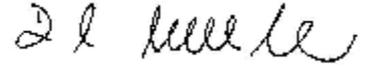
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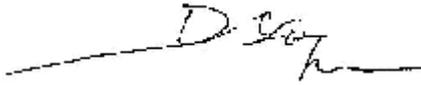
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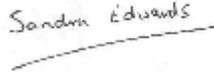
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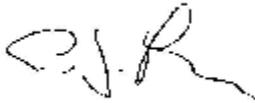
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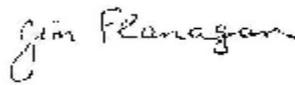
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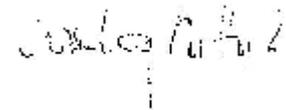
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Summary

Animal breeding and reproduction are at the top of the animal production pyramid and hence define the quality of all animals used in agriculture. Farm animal selection has a great impact on farm animal production as a whole, because the breeding response is cumulative and sustainable. Efficient reproduction techniques, such as artificial insemination, allow genetic improvement to be rapidly disseminated throughout the production chain. Europe has always played an important role in improving the major farm animal species worldwide, but as the 21st century begins, farm animal breeding is at a crossroads.

Opportunities for animal breeding and reproduction stem from the global need for a sustainable increase in food quality, food quantity, and food production efficiency. Worldwide, animal product consumption is expected to grow by around 7% yearly over the next decade, and to keep rising for the next 15-20 years. Much of this increase will be in developing countries. Improved quality notably means safe, healthy food and robust, healthy animals. The overall objective should be to promote breeding of farm animals that is both biologically and economically sustainable, taking into account social responsibility and cultural and regional values. Essential to a competitive Europe with a strong breeding sector are a transparent public engagement, a flexible, open environment also for business with appropriate regulations, and well-educated people. Furthermore, Europe should take on a responsible role in developing new biotechnologies – some of which can only be funded initially from non-commercial (i.e. national or European) resources. New technologies and production systems should be developed in a transparent way and in continuous dialogue with the public. This effort should be supported by research spanning a wide range of disciplines: biology, genetics, chemistry, statistics, computing sciences, economics, ecology, geography, ethics, sociology, farm management… and importantly, their interactions.

The value of animal production (at the farm level) in the European Union-25 (EU25, 2003) is €132 billion, amounting to 40% of the value of agricultural production. The annual value of aquaculture production is €2.8 billion (EU25, 2003). There are nearly 17 million farms in the EU25. In the EU15 alone, farms employ nearly 15 million people. The EU15 agro-food industry has an annual turnover of €600 billion and is the third largest employer with 2.6 million jobs (excluding farmers), mainly in small and medium enterprises (SMEs).

The strategic importance of animal breeding and reproduction is much greater than one might guess from the size and volume of the breeding sector (composed of (S)MEs or small units within large organisations). A conservative estimate of the *gain* from animal breeding to the animal agricultural sector in Europe is almost €2 billion *each year*.

The farm animal breeding and reproduction sector is knowledge intensive. Breeding organisations in Europe spend some €150 million yearly on research, development, and implementation, either conducted in-house or outsourced to universities and other research centres. At the same time, European strength in breeding is challenged by competitors making huge investments in animal genomics and other new biotechnologies and exploiting more favourable agro-environmental conditions (e.g. in the USA, China, and Australasia). If Europe is to maintain its strength and its capacity to meet the often distinctive local needs of the farming industry, then continued investment in research has never been more important. This should be undertaken in a climate of responsive regulation that fosters a responsible and competitive business sector well placed to meet the needs of European citizens.

What we need now is a research agenda focusing on the genetics and genomics of farmed species, quantitative genetics, data collection and management, operational genetics, breeding programme design, numerical biology, the genetics of relevant traits, and the biology of complex biological systems. This should be complemented by research on reproduction required to underpin breeding and the effective dissemination of genetic improvement to all producers. On the basis of the knowledge generated it should become possible to build predictive 'genome-to-phenotype' models, i.e. models for predicting measurable traits on the basis of an animal's genetic makeup. Beyond this we also need to address at population level a number of biological questions related to biodiversity and interactions within and between species, and to maintain a continued focus on reproductive biology and the responsible use of new biotechnologies.

All of this research should be undertaken through competitive research programmes emphasising excellence, flexibility, and the willingness of governments and the commercial sector to co-fund projects. These programmes should take into account the socio-economic context of food production from animals.

The wish to address these important issues with a view for the short- and long-term future is the basis for the creation of the **Sustainable Farm Animal Breeding and Reproduction Technology Platform** (FABRE-TP). This document is the first achievement of the Technology Platform: a vision of how, in synergy with other economic and social players in Europe, a strong European animal breeding and reproduction sector can contribute to animal agriculture and aquaculture in a prosperous and distinctive Europe. We propose this as a common agenda for all stakeholders, from research funding bodies to consumers. Through wide consultation we propose to develop a strategic research priority plan which, if implemented, will deliver our vision of the animal industries by 2025.

Introduction

The domestication of livestock species some ten thousand years ago was a vital step in the development of human civilisation. Over the centuries, domestication evolved into breeding and the genetic improvement of livestock. Nowadays, breeders measure many different animal traits and choose the best animals to be the parents of the next generation. This leads to improvement generation after generation through the increased frequency of desired gene variants in the population. Because the breeding response is cumulative, permanent, and can be spread throughout the production chain, farm animal selection has a great impact on farm animal production.

Europe has always played an important role in improving the world's major livestock and aquaculture species. European breeds are used across the world, and European farmers and breeding organisations are major players on the global market. The European farm animal breeding sector will thus have a great influence on, and therefore responsibility for, the future genetic makeup and characteristics of farm animal populations worldwide.

A conservative estimate of the economic *gain* achieved each year by animal breeding at farm level is **€1.83 billion in Europe alone**. Hence, the genetic gain achieved by breeders is carried over to producers as an economic gain reaching approximately 1.5% of the economic value of EU farm animal production.

Table 1. *Average annual economic gain from farm animal breeding (derived from improved production) in the EU/in Europe*

	Europe (Mio €)
Dairy cattle	430
Beef cattle	70
Pigs (Europe)	520
Broilers (Europe)	610
Layers (Europe)	125
Salmon, rainbow trout, seabass/ seabream, turbot	80
Total	**1830**

The Growing Demand for Food from Animals

There are some 6 billion people in the world today. Despite declining population growth rates, the world population is increasing by about 80 million a year – equivalent to the population of Germany. Around 95% of this increase is taking place in the developing world. The UN predicts that the world population will reach 9 billion by 2050.

Also growing is the per capita demand for animal food, which should continue to rise for at least 20 years. This so-called livestock revolution is a *demand-driven* evolution. The supply of cereals for human consumption should soon be sufficient to satisfy the demand in developing countries, but the supply of animal-derived foods is far from the mark.

The 23% of people living in developed countries presently consume 3-4 times more meat and fish and 5-6 times more milk per capita than people in developing countries. As these poorer people get richer, one of the first things they want to buy is more nutritious and satisfying food, and this generally

means more animal protein. Animal product consumption is thus increasing massively in developing countries, and will continue to do so over the next 15-20 years.

Developing countries are also playing a growing role in animal production. Southeast Asia, in recent decades, has tremendously stepped up its pork, poultry, egg, and aquaculture production. Other noteworthy examples are Brazil, for beef cattle, chicken, and animal feed, and Mexico and Argentina for beef cattle and Chile for salmon. Breeding activities are also on the rise in these countries.

Both Asia and Europe are densely populated and have comparatively little land available for agriculture. In contrast, the Americas (and Oceania) have relatively large amounts of arable land and pasture as compared to population density. This creates for Europe and Asia a permanent risk of food dependence on the Americas. It also creates a 'natural' push to develop foods and food products for –and sell them to- the more densely populated areas. Related policies include farming subsidies in the USA, stimulation of genomics and biotechnology research, and a favourable business and social climate for developing and implementing new technologies.

Importance of Animal Production in the EU

Mankind has been adapting animals for the production of both food (meat, milk, eggs…) and non-food products (wool, leather, bones…) since domestication started. For some farmed fish and shellfish, domestication is still underway. Animal husbandry for other purposes is expected to become more important. Animals have cultural value; they are used for sports and as companions, for maintaining rural areas, and for medical applications (as models of human disease, potentially as providers of organs for transplantation).

The value of animal production at farm level in the European Union-25 (EU25) is **€132 billion**, amounting to 40% of the value of agricultural production (2004). The EU25 counts some 6 million cattle (of which 23 million dairy cows), 103 million sheep, 12 million goats, 4.4 million horses, 11 million beehives, 151 million pigs, 670 million laying hens, 7368 million broilers, and 285 million turkeys (2003). In addition, the annual value of aquaculture business is €2.8 billion (EU25, 2003). The total arable production includes 400 million tonnes of animal feed production, and about 1/3 of the agricultural area is permanent grassland (EU15). Farm animals in the EU consume about 450 million tonnes of feed a year, of which 140 million

tonnes are produced by the compound feed manufacturers. The turnover of the European feed industry is estimated at €35 billion. With EU enlargement, the number of farms has more than doubled (to 17 million), and the proportion of farmers in the workforce has grown from around 4% (EU15) to nearly 8% (EU25).

The EU imports €66.6 billion worth of agricultural products and exports €55.7 billion (figures for 2003), so the balance is negative. The role of animals for leisure and sports (e.g. dogs, horses) is increasing. In the EU15, over 1 million people get their income from horses.

Socio-Economic Aspects of Animal Breeding

Output at Farm Level

The **€1.83-billion** annual gain derived from breeding **in Europe** does not include the export of breeding stock (important in poultry, pigs, and salmon). If this is added, the estimated gain is easily twice as high. The costs associated with this economic gain are relatively small in relation to the improvement achieved, as genetic improvement is cumulative and investments in small populations at the top of the breeding pyramid are multiplied down the pyramid to the base level: animals for commercial production.

A Competitive Global Market

Farm animal breeding and reproduction operate in a competitive global market with very low margins. Changes in market shares can occur quickly, especially in areas where a handful of companies serve 90% of the global market. Small differences in performance, cost price, or knowledge implementation (e.g. exploiting genomics) may bring about such changes. As a result, smaller companies might not survive the competitive pressure in a fast-changing marketplace with evolving technologies. This applies notably to ruminant breeding, which is mainly still organised nationally. Here, cooperation between European players is required.

Maintaining the strong position of breeding in Europe is thus not automatic. It will require considerable efforts from breeders, but also the positive engagement of researchers, governments, funding bodies, legislative bodies, and European society as a whole.

A Knowledge-Intensive Sector

The farm-animal breeding and reproduction sector is knowledge intensive. This means not only that the sector exploits knowledge to provide the world with breeding stock, but also that the knowledge developed is or can be used to meet local, niche, or cultural demands inside or outside Europe. The past success of European breeding owes much to its longstanding close ties with universities and research institutes, fostering the dissemination of knowledge to the farm and individual breeder level. In some cases (e.g., dairy cattle) and some countries this dissemination has been very successful, but it still needs to be improved in order to take other situations and rapid changes in animal breeding and reproduction technology into account. The knowledge exploited includes not only genetics, genomics, physiology, reproduction, statistics, and computing science, but also – importantly – economics, animal husbandry, storage and analysis of large datasets, and efficient infrastructure design. Benefits of co-operation over species have been large. The aim is to achieve higher

production levels and better product quality while improving animal health, reproduction, other physiological characteristics, and/or feed efficiency. The reproductive characteristics of the animals used largely determine the spread of genetic progress and the organisation of breeding schemes.

Breeding organisations in Europe spend around **€150 million** yearly on research, development, and implementation (in-house or outsourced to institutions such as universities). This includes money spent on estimating breeding values and executing breeding programmes, but not the cost of steps further in the chain, like multiplication and commercialisation.

Actors outside Europe (in the USA, China, and Australasia, for instance) are making huge investments in genomics and other new biotechnologies. Research and business conditions are more favourable in the countries concerned than in Europe, and there tends to be a more positive attitude towards progress made possible by new technologies.

Europe must also develop knowledge and understanding of new technologies with no immediate application, so that we are well placed to understand their benefits and risks. In developing these technologies, it is essential to ensure close collaboration between research and government as well as transparent inclusion of stakeholders from industry and society.

Emerging Technologies and Societal Concerns

Farm animal breeding operates in a sensitive area because it touches upon important issues: food, health, animals, selection, genes… This sensitivity is reflected in societal concerns related to food safety, ethics, cultural value, genetic diversity, animal welfare, and 'naturalness'. Animal breeders are actively seeking to address these concerns, both internally amongst specialists and through dialogue with policymakers and society. Here are some of the issues that they are addressing:

Sustainability

Breeders have a role to play in promoting sustainable worldwide animal production (a widely discussed concept which emerged in the last decade and was developed notably in the EU-funded SEFABAR project). To play this role optimally over the next two decades, the breeding sector must be both economically sound

and attuned to societal needs and demands. This notably means taking into account aspects such as biodiversity, environmental protection, food quality and safety, animal health and welfare…

European breeders have been addressing the ethics of animal breeding, notably by producing educational material on this topic and by developing ethical codes such as a Code of Good Practice for Farm Animal Breeding Organisations (Code-EFABAR). Centring on sustainability, this Code aims to enable breeding organisations to become more transparent.

Animal Welfare

In twenty years, most livestock production (pigs, poultry, dairy cattle, beef cattle) will probably be in large-scale units, though still mainly family owned. Animal welfare in this situation will be a high priority and animal breeding can contribute to it. In this context, attention should be paid to developing efficient information management systems for health monitoring, health detection, etc. Similarly, very little is known of the welfare of the domestic aquaculture species today.

New Technologies

Globally, there is active competition for new technologies that may directly or indirectly affect the future of animal production, including breeding. Some non-European countries (e.g. New Zealand, the USA, Argentina, Brazil, China) are rapidly developing research on – and in some cases implementation of – new reproduction and cloning technologies (somatic cell nuclear transfer, i.e. "Dolly-type" cloning) and genetically modified animals. Other foreseen applications of the new biotechnologies in animals are in the medical field: animal models, animals as bioreactors, and animals for xenotransplantation. Although the development and possible use of such applications are beyond the direct scope of breeding organisations, Europe must be in a position to objectively evaluate these technologies and consider their potential.

Control over Future Decisions

As breeding is a competitive global market, cloned or transgenic (genetically modified) animals developed outside Europe or products derived therefrom are bound to find their way eventually to the European market. Currently, however, knowledge of technologies such as cloning or transgenesis (gene transfer) in farm animals is rapidly disappearing from Europe. For Europe, the only way to stay in control of its own decisions is to keep pace with international developments. Europe may want to close its borders to technologies it does not appreciate, but for this it will need sufficient knowledge and high-level scientists to support its claims internationally, e.g. in World Trade Organisation (WTO) negotiations.

There are other good reasons why Europe should develop further its expertise and skills in new technologies. The importance of this type of research for the non-food area is potentially so great that Europe cannot afford to miss out on new developments. Ultimately the efficiency of new technologies may increase until there is no impact on animal health, animal welfare, or the environment.

In conclusion, funding of research on new technologies should continue in Europe, even if we cannot predict today whether we will need this expertise to develop our own future (and what that future will look like) or to protect ourselves in global trade negotiations. This funding should be from non-commercial resources (national, local, European), so that Europe can make a real and unbiased choice when the time is right.

Transparency and Dialogue

Transparency is of the essence, both in breeding and in the development of new technologies and pathways. Also essential is a continuous dialogue with the public as technologies are being developed. We need to discuss how increasing knowledge and the exponentially growing power of computer analyses can be applied in order to achieve balanced breeding effectively. We need to tackle questions such as: can finding the right balance enable us to meet global challenges? Can genomics be a powerful tool for this purpose? How can breeding knowledge and the organisation of breeding be exploited in order to satisfy the growing demand for animal products and to meet specific needs in relation to emerging economies, food safety, food supply, and the maintenance of diversity in small breeds?

Links with Animal Populations and Culture

Breeding is working with animal populations. In the case of most species this means that there is a close link with national breeds and that breeding is often organised nationally. Animal breeding is not only about animal products. Especially in the case of extensively farmed grazing animals, it is also about domestic animal biodiversity, food security, rural landscape management, and cultural values. These aspects are important in Europe.

Organisation of Farm Animal Breeding

Farm animal breeding is organised at different levels, from farms to breeding companies to breeding organisations up to the level of regulatory bodies providing national and international (e.g. EU) regulations. The organisation of farm animal breeding differs significantly according to the species.

In poultry and fish farming, there are relatively few breeding organisations worldwide, as breeding work is knowledge intensive and relatively expensive.

In the case of ruminants, farmers are often organised co-operatively for technical services, representation activities, and breeding. Pig breeding is in an intermediate situation.

In recent decades, only collaborative or specialised organisations have been able to breed livestock effectively, taking into account the latest scientific developments, using powerful computing systems and sophisticated estimation programmes, maintaining huge pedigrees of animals with their performances and biodiversity, and exploiting reproductive technologies. Yet there are no very big players in animal breeding. The organisations involved are (small or) medium enterprises or small units in larger organisations.

Poultry and Aquaculture Species

It is possible to concentrate breeding of small farm animals because the number of offspring per parent is high. This is what has happened. Margins being extremely low for eggs and meat from these species, breeding costs have been reduced as much as possible. In many cases former breeders have become multipliers (a step in the dissemination of breeding stock), outsourcing the selection work to another company. In poultry, for layer and broiler chickens and turkeys, 2-3 organisations are responsible for over 90% of the global breeding stock in each market. Aquaculture, a young sector, is developing in the same direction. Here, the number of species that can be farmed is rapidly increasing. Selective breeding is being applied to salmon, trout, seabass, seabream, and turbot, as well as other aquatic species such as shrimp and oysters. Breeding programmes for recently domesticated cod strains are now beginning. It is necessary to develop breeding and reproduction of additional species in aquaculture, so that closed selective breeding schemes can be initiated and the over fishing of wild stock can be avoided when the demand for aquaculture products increases.

Ruminants and Pigs

In the breeding of ruminants (cattle, goats, sheep) and still, to some extent, pigs, the animals' limited reproductive output means that a large number of breeding units (on farms) are needed in order to disseminate desired characteristics from elite animals at the top of the breeding pyramid. In addition, cows on dairy farms are the mothers of potential future breeding animals and are hence also a part of the breeding chain.

The breeding of small ruminants such as sheep and goats is also specialised. The farmers of these species often live in marginal areas, far from the market and with a more limited access to technology than in the case of other species. Small-ruminant farming is often organised in a weaker co-operative system than for cattle. The importance of these species is likely to increase in the future because of their important environmental impact. New technologies in breeding and reproduction have not yet had much impact and should therefore be stressed.

In pigs, many farms are involved in disseminating top breeding animals to the farmer who grows the pig. Breeding programmes are often based on crossbreeding schemes integrating a dissemination level and a core breeding level.

In ruminants and pigs, most breeding organisations are cooperatively owned by farmers. The organisations based in Europe are world leaders for their species. They are often SMEs operating in their native language, organised in national umbrella organisations. For disseminating desired genotypes, the national or local organisations of ruminant farm owners are internationally co-ordinated by a single international institution, based in Europe, created to provide services, mainly in animal breeding, on a larger, international scale. The largest pig breeding organisations in this sector are private or cooperative European organisations with a major impact worldwide.

Ownership

The purchase price of an animal includes its breeding rights, so the reproduction rights for an animal belong to the animal's owner. There is no animal equivalent of plant breeders' rights. The population structure of breeding makes such protective systems very sensitive to 'cheating'. Private investment in research, on the other hand, should be stimulated by dedicated protection of relevant findings.

It is important to strike a good balance between knowledge sharing and the protection of newly developed knowledge and tools. Patents are not commonly used in breeding – existing methodologies and knowledge should not be subject to 'broad claims' and 'new claims' that would hamper access to methods already applied or described and discussed openly at round tables and conferences, in scientific magazines, etc.

Structural Change

The number of main organisations active in farm animal breeding and reproduction varies considerably in the EU. Yet across the EU there are many thousands of smaller pedigree breeders, most of whom participate in larger breeding programmes organised by some of these main organisations.

In the breeding of all species there will likely be a trend towards concentration, i.e. towards fewer, larger breeding enterprises.

Regulatory Aspects

The organisation of animal breeding and reproduction is under permanent supervision by – and interaction with – regulatory bodies providing national and international regulations (e.g. EU authorities and ICAR, the International Committee for Animal Recording). Interaction with these bodies is crucial to promoting the harmonious development of animal breeding and reproduction practices, especially in ruminant farming with its open breeding structure.

A Vision for Sustainable Breeding and Reproduction

Animal breeding and reproduction have a great contribution to make to a future sustainable animal agriculture. Many opportunities are open to the animal breeding and reproduction sector for improving the biological and economic efficiency of food production and increasing food supply[1]. These opportunities are particularly attractive in a sustainability perspective. The sector is intimately linked to all three pillars of sustainability: **Consumer, Environment, and Economy**, through its interactions with societal developments, its implications for biodiversity and the environment, and its contribution to economic growth. How these three pillars will develop in the next twenty years and how sustainable breeding in the EU will fit into the picture are questions that must be addressed.

Sustainable breeding and reproduction means balancing:

- safe and healthy food
- robust, adapted, healthy animals
- biodiversity
- social responsibility
- a competitive and distinctive Europe

and must include new prospects for animal production in Europe. When it comes to developing new technologies, transparency about the developments and an open dialogue with society are prerequisites.

Integration into Animal Agriculture

Traditionally, animal agriculture and aquaculture are fragmented into distinct activities and focuses: animal nutrition, animal waste management, food science applied to animal products, animal welfare, animal management, and animal breeding and reproduction. Given the challenges facing animal agriculture and aquaculture today, we believe that a much higher degree of integration is needed. In our vision, integration will affect all levels and will certainly influence the future of animal breeding and reproduction, as outlined below.

Safe and Healthy Food

Product Quality
In a "fork to farm" production system driven by consumer needs, quality in the broadest sense (food safety, nutritional value, sensory and technological quality) becomes one of the most important drivers. Safe and wholesome food is clearly the first requirement. Beyond safety and for all animal products, product quality improvement will be a major issue. This is a significant shift from the food sector's position in the last century, when improving the level of production was the obvious goal of a supply-oriented production system. In the modern context, nutritional value and human health features (e.g. the fatty acid composition of meat and milk, the nutritional quality of eggs) can become targets for animal breeders, as can sensory qualities such as tenderness, flavour (importantly, this includes boar taint), visual appeal, and processing characteristics. The importance of breeding systems and new technologies in protecting the quality and enhancing the economic efficiency of local and typical productions deserves full consideration.

Zoonoses
Farm animal breeding and reproduction have a role to play in decreasing the incidence of zoonoses. The opportunity to breed animals that are resistant to spreading zoonotic diseases or have a generally improved immune system should be seized, as it will greatly improve food safety. Both animal and human health will benefit.

No Residues in Food
Ideally food should contain no residues. This is an important aim. By selecting animals that are more robust and able to adapt easily to the production environment (e.g. feeding system, climate, housing/grazing system), it will be possible to reduce the need for medicines and thus the risk of residues in animal-derived food.

Safe Gene Dissemination
The safe dissemination of animal genes is a major issue. The risk of transmitting diseases through animal, semen, egg, and embryo transport has increased with increasing farm size and the internationalisation of trade. It is essential to minimise this risk. Artificial Insemination and embryo transfer have contributed a great deal towards this goal, but there is room for further reducing the disease transmission risk and ensuring safe transport of genetic material by improving the health guarantees of this material. The role that existing and new reproduction technologies can play in the (international) transport of breeding material should thus be weighed against the ethical dimension of using certain technologies (e.g. embryo technologies). Specific Pathogen Free (SPF) production of breeding animals results in animals free of certain diseases, which in turn leads to improved human and animal welfare.

Robust, Adapted, Healthy Animals

Animal Welfare
Breeding organisations ensure the health and welfare of the animals they keep and select. They are engaged in the search for selectable traits that are indicative of species-specific animal welfare. New biological insights into brain function, the genetics of behaviour, and physiological indicators of stress and well-being will provide new tools enabling breeders to handle welfare traits more objectively than at present.

Adaptability
Breeders produce animals for a wide range of production environments, from extensive and/or organic systems to more intensive systems on larger farms (which continue to get even larger). Breeders want to be able to improve the level and efficiency of production in each of these environments. It is essential that animals remain healthy and productive under this wide range of environments and with

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[1] This concerns ruminants (e.g. cattle, goats, sheep), horses, pigs, poultry, and aquaculture (e.g. farmed fish, shellfish)

reduced human interference (labour costs are the main costs in farm animal production, along with feed). It is now common for breeders to test animal performance in more than one environment, but new knowledge on how animals adapt will enable breeders to take novel aspects of production into account more effectively in breeding programmes. Over the next twenty years there will be more large-scale units and new technologies for which an efficient information management system will be developed. Aims will be to facilitate selection of animals for adaptation to these systems and to use technology to support balanced breeding programmes.

Domestication of Fish
Most farm animals (and companion and sporting animals) were domesticated thousands of years ago. This is not the case of aquaculture species. Here, the domestication process has just started. A lot of work has to be done towards improving the reproduction of aquaculture species and towards domesticating species that are now only caught in the wild.

Disease Resistance (general and specific)
Breeding may contribute to robust and healthy animals by selection for more general and specific disease resistance as is done for aquaculture species today. This should result in less use of medicines. Optimising the use of medicines and vaccines according to an animal's genetic makeup represents a significant development opportunity.

Balanced Breeding and Biodiversity

Balance
It is necessary to further increase production levels so as to lower cost price and to ensure an adequate supply of meat, fish, eggs, and milk for a fast-growing human population demanding more of these products. Yet especially in Europe, breeding cannot be driven by production efficiency alone. In defining breeding objectives, it is necessary to strike a good balance between the production level, animal physiology (welfare, behaviour, health, reproduction), and population fitness. By learning more about animal genes and physiology and by exploiting greater computing power, it should be easier to balance these multiple breeding objectives. To achieve this optimally, we need more knowledge and better tools in areas such as the basic biology of traits and their interrelationships and data handling. Also essential is the improvement of genetic and reproductive tools with regard to precision, ease of use, and cost.

Biodiversity
Breeding programmes are designed to make optimal use of existing genetic variation between and within populations. Breeding organisations must contribute to maintaining genetic diversity in their breeding populations. They must monitor and control the rate of inbreeding and genetic drift. In animal populations with an open structure (e.g. cattle), the 'effective' population size is much smaller than the actual population size. A research opportunity is to better understand the interaction of biodiversity and genetic variation. This will foster knowledge-building in diverse areas, such as the co-evolution of hosts and pathogens and animal adaptation to climatic differences or variable nutrient availability. It will also

contribute to defining appropriate levels of biodiversity, identifying in small populations 'rare' gene variants whose preservation should be

prioritised, and protecting genetic diversity in populations used for large-scale production.
In the coming years, more attention will have to be paid to managing (as distinct from conserving) animal genetic resources, particularly given the sometimes narrow genetic base of pigs, poultry, and dairy cattle, and the concentration of breeding strategies and selection in very few hands.
Furthermore, it is important to bear in mind that biodiversity preservation is the key to preserving future breeding opportunities. It is essential to maintain sufficiently diverse gene pools because we cannot foretell the changes that might affect the social and economic driving forces of animal agriculture. Nor can we predict the evolution of biodiversity-related ethno-zootechnical issues that influence the link between farm animals and society.
The preservation of biodiversity is also important for conserving and improving local breeds, which are very significant in marginal areas. The need is to protect these breeds by increasing their production and standardising the quality of their products. Objectives will be to defend the environment of marginal areas and to maintain the efficiency of animal farming in less favourable areas.

Social responsibility

Environment
There is scope for selecting animals better suited for maintaining biodiversity under changing climate conditions. A major achievement of animal breeding in recent years, and one with a highly favourable effect on the environment, is the improvement of feed efficiency. When animals make more efficient use of nitrogen and phosphate, this minimises the output of these elements into the environment. The main contributor to improved feed efficiency is improved feed conversion. Yet there is room for further improvement of this process, especially in farmed fish. Progress will require new knowledge on the genes and pathways that may contribute to improving the European environment while an animal's production level is increasing. Opportunities for feed efficiency improvement exist in all farm animals, from fish to cattle. This requires better knowledge of the digestive system and of nutrient metabolism. Of particular interest are the genes whose expression is regulated by nutrition. When exploiting such knowledge in

animal selection, it is necessary to take into account animal product quality and both beneficial and unfavourable environmental outputs.

Animal breeding contributes to the environment in yet another way: through selection of animals well adapted to their environment and interacting favourably with it by grazing and pasturing. Such animals contribute significantly to ecosystem maintenance. The selection of genotypes for the maintenance of the environment is fundamental in many European geographical areas, especially mountain and Mediterranean areas.

Animal Welfare: Integrity

Animal integrity is defined as "the wholeness and completeness of the species-specific balance of the creature, as well as the animal's capacity to maintain itself independently in an environment suitable to the species." Most farm animals have been domesticated for thousands of years and as such have been adapted to an environment of co-existence with humans. They are easier to handle and able to reproduce in captivity, under conditions where food is abundant and there are no direct predators. Breeders must keep a balance between the intrinsic characteristics of domesticated species, their welfare, and improved production.

(Contributing to) World Development

The global demand for animal-derived foods is increasing. European breeding organisations play a major role in providing breeding stock globally. For pigs, aquaculture species and poultry, which are reared in relatively controlled environments, this has generally been a huge success. The history of cattle breeding, however, is littered with mistakes. High-productivity European breeds are not always suited to more extensive environments characterised by a different and sporadic food supply and by various climatic and disease challenges. It is possible to learn from these mistakes. In global development programmes, the knowledge and organisational skills of European breeders could be adapted to meet local needs in developing countries.

New breeding schemes require multiple-character selection based on both production traits and other important traits such as resistance to disease (sanitary quality and animal welfare), fertility, and longevity (animal welfare). At the same time, there is a need to conserve biodiversity through the development of appropriate breeding strategies in rare ruminant breeds.

A Competitive Europe

A Strong Breeding Sector

A prerequisite to breeding in Europe is the survival of the breeding sector. Major companies have premises for breeding and reproduction outside Europe, where research can often be more easily funded and carried out. There is a constant push to move away from the head offices in Europe in order not to lose market potential and ultimately lose out in the competition. Every year breeding companies disappear or amalgamate. When companies move away, they will not come back. An important challenge and opportunity is to keep the breeding climate in Europe challenging and interesting enough to maintain businesses here. Breeding needs profitability at all levels and requires active participation of farmers in

order to test animals for desired characteristics and to disseminate those characteristics. This is feasible only if such endeavours are economically sustainable. It is crucial to preserve the livestock system by maintaining and/or increasing the efficiency of breeding also in small-scale animal farming. Many of the new EU member countries have a tradition of small-scale aquaculture, which needs to become more efficient in order to compete. Breeding is a global activity, and European businesses have gained leadership in the breeding of several farm species. Yet the market remains competitive and as technology developments continue at a breathtaking pace, European breeders must not be complacent. There are structural weaknesses in Europe compared to other global players, as breeding is often organised nationally. Given the existence of 25 different countries in the current European Union, this is a natural disadvantage for European animal breeding. Further strategic partnerships in research, development, and business across Europe will be increasingly important. Research opportunities will arise in operational genetics, numerical biology, animal recording, data management, and high-throughput biological research. If Europe is to retain its competitive strength, there must be sufficient support from research funders to ensure that the basic and strategic research opportunities are seized. European public funding should play an important role in this context, helping to foster integration of research activities and co-ordination of research and innovation policies.

It is essential to bear in mind that the changing world will demand careful but *fast* adaptation of farm animal production systems and hence of farm animal research and breeding in its broadest context.

Transparent Public Engagement

New technologies, goals, or practices will be part of the road to the future. In some parts of the world people are already applying food production technologies that Europe considers unacceptable. This trend towards parallel development paths may well continue, so Europe must develop alternative approaches if its agriculture is to avoid facing even greater competition than it does today from cheaper imported foods. One promising pathway might be a trend towards differentiated foods (e.g., speciality foods, organic foods), as food production in Europe is likely to develop towards quality instead of quantity.

Alongside the development of new technical solutions to breeding problems, it is important to involve specialists in ethics to support careful interaction with society as a whole. It is vital to realise and take into account which breeding activities are in line with what European citizens want animals to do and produce and what they consider inappropriate. Transparency about breeding work and research developments is a key issue for farm animal breeding scientists and breeding organisations. Animal breeding strategy over the next twenty years must include a commitment to communicate with civil society. In the past, a lack of information has sometimes given new breeding technologies a negative public image.

A Flexible, Open Environment

For European breeding organisations, competition at the global level is strong. Unlike breeders in the largest competitor country, the USA, European

breeders must deal with a multiplicity of scientific, funding, and regulatory environments within Europe. European breeders need a flexible, open environment in order to continue their business and to develop and implement the schemes needed for the future. They are therefore in favour of initiatives such as regular and timely consultations with regulatory agencies, dedicated to finding workable yet safe solutions for animal transport and new technology implementation (guided by ethical and safety considerations), investigating specific conditions for minor species or species under development, and creating the same conditions for imported material as for European material.

Well-Educated People

For a knowledge-intensive sector, the education of students and hence of future science and industry leaders is important. The growing complexity of animal breeding makes this especially true. Today the sector requires a knowledge base combining largely quantitative science with molecular genetics and genomics, as it pogresses towards the day when it will be an industrial user of predictive biology.

Education, in the future, should be a more collaborative endeavour where public and private bodies cooperate more closely.

A Distinctive Europe

Rural Areas

Farm animals, especially ruminants but also horses, have an important role in maintaining the European rural landscape, e.g. in keeping areas clear to prevent fires. Only a few local breeds are now still part of that landscape and add to its diversity across Europe. Therefore, we need to maintain those breeds that fit with the landscape and, in harmony with the environment, yield high-quality local products. We need to breed them to maintain the landscape whilst improving their economic sustainability.

To reach these objectives, it will be necessary to consider breeding goals and technologies for extensive systems. The value of the resulting breeding system will be enhanced by the enormous importance of extensive livestock farming not only for production but also for its environmental and social benefits. Aquaculture production has another value for the rural areas as it is often situated in such areas and can therefore assure that work-places are secured there.

Regional Products

Europe is a diverse continent with typical products related to local breeds, local environment or climate, or local habits or history. Consumers often go for a value-for-money product, but increasingly they appreciate the perceived added value of regional products. In many situations in Southern Europe and mountain areas, breeding will have to be planned to improve the distinctive qualities and local characteristics of animals. This will lead to a differentiation of food products.

Social/Cultural Aspects

European animal production is also important for the vitality of the countryside. When farmers disappear and holiday homes take over, the social infrastructure can suffer (e.g. schools, shops, public transport). Cultural values may open a market for some higher-

value niche animal products, appreciated by consumers when the origin of the food is part of its attraction (e.g. when eating for pleasure in a restaurant or cooking a special meal).

A Diversity of Benefits

Animals for Many Purposes

With the standard of living increasing and more time available for most people, animals for pleasure and leisure are a growing industry. In addition to companion and sporting animals, there is a growing trend towards 'hobby' farming. Animals will also be bred for social purposes, e.g. for 'animal therapy' or for helping to rescue people in an emergency. Breeding for the right type/character of animal for the right purpose may be a new, promising prospect for breeders.

Fibre and Skin

Wool, leather, and skin are among the traditional farm animal products. They used to be necessary items for clothing, but nowadays they are used for their 'naturalness' (e.g. wool) or for the specific advantages of the product (e.g. leather). Breeding sheep or other fibre animals for typical products, like natural coloured wool, is an increasing niche market.

Animal Biotechnology

The combined advances in genetics, embryology, and stem cell research open the prospect that high-added-value products for agricultural, medical, and technical applications will soon become a reality. The major applications will be in the use of highly specialised animals for drug production (e.g. in milk), for xenotransplantation, or as animal models in research on human diseases.

In the future, animals may become precious tools for modelling human disease and developing new therapeutic strategies. Such approaches will both complement and inform studies based on human cell/tissue cultures. To make such applications possible, it will be necessary to develop robust embryonic stem cell lines capable of self-renewal in culture and to refine the technologies used for cloning and transgenesis. These same technologies will be valuable research tools enabling scientists to gain deeper understanding of livestock and companion-animal embryology and reproduction.

A challenge in the next two decades will be to integrate and potentially exploit these novel technologies in a society-friendly manner. For this it is essential to build the knowledge base and expertise required to provide technological guidance, quality control, and safety.

An Agenda for Research and Technology

Quantitative Genetics and Operational Genetics

Some inherited traits, such as milk yield or daily gain, are controlled by many genes. In an animal population, different animals will have different combinations of gene variants affecting a given trait. This leads to quantitative variation of the trait within the population. Such traits and the underlying genes are the focus of quantitative genetics. Over the past fifty years, most improvement in the quality and efficiency of farm animal production has been due to the application of quantitative genetic methods. For instance, the International Bull Evaluation Service (Interbull) maintains and provides access to a huge body of genetic animal evaluations from the most advanced countries. Its ranking of bulls according to their 'genetic merit' facilitates the genetic market worldwide.

Operational genetics is the application of genetics to breeding, for example in designing breeding programmes and optimising selection schemes to ensure maximum genetic gain while minimising inbreeding or undesirable trade-offs of selection.

If breeders are to maintain and build upon the enormous genetic progress made in past decades, they need the support of research focusing on the further development of complex statistical methods and computer algorithms for coping with multiple traits. They need information from new sources such as genomics and the study of how animals adapt to specific environments. Attention must also focus on the more complex, non-linear, and difficult-to-measure traits such as disease resistance, longevity, and robustness, as well as on new and emerging traits. Alternative selection schemes should also be envisaged for the analysis of non-additive genetic variation.

Advanced Modelling for Management Purposes

Quantitative genetics has a favourable 'side effect' of which people are not always aware: extensive modelling of complex phenotypes (biological traits) provides interesting and important information about environmental influences on these phenotypes and makes it possible to predict unobserved phenotypes. It will be important to incorporate this and all relevant knowledge into advanced management tools, which will notably increase the return on investment of extensive data recording schemes. Current efforts in the field of milk recording (test-day models) are just the start of a whole new range of research opportunities. Future research in statistics and computing sciences will be required to optimise current methods and procedures. As an on-farm management system develops, a challenge will be to link it to more integrated, multi-level systems.

Phenomics

Phenomics means the measurement of animal phenotypes. Currently animal breeding programmes can only improve measurable traits or traits genetically related to measurable traits. They rely on

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The Digestive Tract

Food safety, the biological and economic efficiency of livestock farming, and hence the environmental footprint of livestock production are all profoundly affected by the biology of the digestive tract – the internal tube that extends from an animal's mouth to its anus. Food digestion and waste excretion are complex and energetically expensive processes.

The digestive tract is also home to huge numbers of other species (the microflora). These are mostly harmless or even positively desirable. For example, the microflora of the rumen of grazing animals such as cattle and sheep is actually essential to digestion of their forage diets. The average human is said to carry about 1 kilogram of bacteria, and the figure would be much higher for a cow.

The gut can also provide an excellent environment for some less desirable inhabitants. It can harbour organisms associated with food-borne infection of humans, such as Campylobacter, Salmonella, or E. coli, sometimes without even making the host animal sick. Importantly, the gut can also be a site of infection by pathogens and parasites. At best, these unwelcome inhabitants drain nutrients that could otherwise be used for food production. At worst, they can result in serious disease, even death. When an animal recovers, the efficiency of the gut may be permanently impaired, reducing the animal's vitality for the rest of its life.

Because the gut can be a site of infection it has a complex immune system that can generally recognise 'friend from foe'. Yet we also know that there is genetic variation among animals in how well they can resist infection. For example, chickens display variable resistance to Salmonella and sheep are variably resistant to worm infection. Much less is understood about variation in other aspects of the gut, for example its energy use or the efficiency of digestion or the transport of nutrients across the gut wall.

The digestive tract is an important and poorly understood biological system important to our vision goals of 'safe and healthy food', 'robust and healthy animals', 'sustainable breeding' and 'a competitive Europe'. Research opportunities related to the digestive tract might include:
- *developing a better understanding of genetic variation in the immune system in the mucosal lining of the gut;*
- *characterising the heritability and genetic basis of efficiency of digestion and nutrient capture in both health and disease;*
- *understanding interactions between the gut and the normal 'healthy' microflora, and their role in digestion;*
- *dissecting the molecular biology of host-pathogen interactions and the response to infection.*

characterising animals for production, quality, and welfare traits on the basis of limited numbers of laboriously collected records. The entire selection system for ruminants, through which many traits have been improved, is based on this traditional approach, embodied in a manual used throughout Europe and on other continents: the 'ICAR Guidelines for Animal Recording'. In the future such methods are likely to be complemented by high-throughput automated recording systems, on farms or in processing factories for example.

An important future research focus will be the estimation of carcass meat content by means of automated image collection. Accurate measurement of many other meat traits (e.g. colour, fillet yield) currently requires animal slaughter, but new techniques have emerged (Near Infrared Spectroscopy (NIR), ultrasound and computer tomography) that will allow such traits to be recorded on the breeding animal. This will increase the accuracy of selection and hence, the genetic gain. Ultrasound techniques were successfully implemented in pig and beef cattle breeding in the 1970s and can be further developed in other species. In dairy animals, more sophisticated techniques for the recording of milk yield and composition are necessary in order to continue improving the production efficiency and nutritional quality of milk and milk products through selection.

Much remains to be learned about how biological attributes and genetic features influence many sensory traits of meat. For example, are variations in meat texture due to muscle fibre number, fat content, the amount of connective tissue, or to all of these factors? Before breeding programmes can tackle such traits, we need to know which measurements are needed to describe them and how to interpret those measurements.

Identification and Traceability Technologies (ID)

Animal identification is the cornerstone of selective breeding programmes. In the absence of accurate identification, no pedigree can be established and all information on the animal is lost.

The ability to trace an animal from birth through to a finished product (meat, milk, eggs, wool, leather) is crucial in the battle for safe food, in controlling contagious diseases, identify fish that have escaped into the wild, and in the effort to inform consumers about food attributes such as country of origin, animal welfare, and genetic composition. The development of animal breeding systems for ruminants and pigs will make full use of technical improvements in physical identification: Ear-Tag systems, Radio-Frequency Identification (RFID), electronic boluses… Long-term research should be devoted to all these methods. Another approach that has huge potential is the use of genetic markers for individual identification. This approach should prove particularly useful in aquaculture and poultry farming, where physical identification at birth is difficult to impossible, but it is also applicable to other species. Research is thus needed in areas such as high-throughput genotyping (i.e. genetic marker typing) and DNA chip technology in order to address issues of practicability, cost, and access. It is also urgent to explore how new technologies might be applied to traditional identification systems having an immediate and wide application. Furthermore, all actors in the field must collaborate towards ironing out the relevant legal and regulatory aspects.

Genomics and Beyond

An organism's genome is its genetic material (DNA). Animal genomics, broadly defined, is the study of animal DNA, its organisation into genes, the roles and interactions of gene products (mostly proteins), the control of gene expression, and ultimately all downstream impacts on animals, their traits, and their interactions with the environment.

The sequencing of the human genome was a milestone in the development of modern biotechnology, opening new avenues for understanding the control of complex traits at a molecular level. The genomes of several farm animal species (cattle, pig, rabbit, and aquacultural species) are also being sequenced and analysed. This will facilitate the integrated analysis of biological functions.

At sequence level, genomic research is yielding genetic markers for selection, pedigree control, and traceability. It is facilitating the identification of trait genes for use in breeding programmes. Beyond this level opens the whole new realm of "omics" research: transcriptomics (focus: expressed genes), proteomics (proteins and their functions and interactions), and metabolomics (metabolites and metabolic pathways). This research is bridging (part of) the gap between 'structural' genomic knowledge (markers, maps, sequences, genes) and everything we hope to learn by exploiting it. It provides a bridge to nutrition, health, and more. It is yielding precious knowledge on a wide range of processes related to health and food safety, such as acquired resistance to contamination through gut health or the long-term effects of an altered maternal diet (foetal programming) in both animals and humans. The application of such knowledge (in marker-assisted breeding programmes, for instance) will contribute to improving animal health and food safety, animal welfare, and the biodiversity of breeding populations. In the long run it will boost the competitiveness of European farm animal breeding.

Functional Genomics

This area includes transcriptomics and proteomics. It aims to elucidate gene functions. Transcriptomics uses powerful tools (e.g. microarrays: arrays of material resulting from gene transcription, the first step in gene expression) to study simultaneously the expression of many (ultimately all) genes in a genome in various situations (specific developmental stages, environmental stress…). Proteomics exploits various technologies to study which proteins are present in – or secreted by – different cells under different conditions, and also looks at protein interactions.

Functional genomics is used to study genes that contribute jointly to a specific function as part of the 'interactome' (the whole set of molecular interactions in cells). This notably includes networks of interacting proteins, structural and mitochondrial DNA, and inhibitor RNAs (RNA is quite similar chemically to DNA; it plays multiple roles, notably in gene expression and its regulation). By combining multiple approaches and tools, it should eventually be possible to build models linking together large numbers of genes and their products, in order to understand the impact of gene variation on animal traits, mediated through the relevant metabolic pathways. To achieve this, a considerable research effort is needed, yielding better understanding of animal biology on the basis of knowledge obtained from the genomes of model organisms and humans.

Exploring Within-Species Variability

To allow effective selection of animals via genomic approaches, it is necessary to explore within-species variability and to quantify factors such as linkage disequilibrium (the tendency of genetic features that are close to each other on the genome to be inherited together, and thus frequently to be found together in the animals composing a population). Effective genomic selection requires the development of tools for genotyping animals by marker typing or direct sequencing. It requires improved tools for phenotyping animals more exhaustively and quickly (see "phenomics") so as to identify genes that control variation of multiple traits. We also need to develop strategies for predicting phenotypes on the basis of genotypes. Here research should notably focus on the genetic control of variation in gene expression and the identification of genome regions undergoing epigenetic modifications such as imprinting. Given the strong negative impact of inbreeding on reproductive and health traits, we need to find ways to reduce the inbreeding coefficient in pigs, poultry, aquaculture species, and dairy cattle.

Exploring Between-Species Variation

By learning more about between-species variation, it will become clear which vital processes program which functions in animals. This will enable breeders to identify animals yielding healthy animal products without this being detrimental to their own health. With genome-scale sequencing of domestic species, between-species comparisons (including comparisons with mouse and human sequences) will make it possible to identify variability 'hot spots' in genes and/or genome regions so as to focus the search for single nucleotide polymorphisms (SNPs) responsible for substitutions in protein sequences in domestic animals (SNPs are sites where a single 'letter' in the 'text' of a gene is variable).

Numerical Biology

Future biology will increasingly require the analysis of large volumes of data (e.g. genomic data). Better numerical methods for analysis and modelling are needed to address a whole range of biological problems from the molecular to the ecosystem level. Identifying functional variants in DNA sequences or differentially expressed genes on microarrays, analysing host-pathogen interactions in farm animals populations, are just a few examples among many.

There will be an increasing need for better numerical models of biological (sub-)systems. For example, scientists currently use separate models to predict protein folding from amino acid sequences and the spread of disease from epidemiological data. A more elaborate model would predict the impact of designed changes in an immune response gene on the frequency of disease epidemics in domestic animals.

As the need for numerical analysis and modelling spans all areas of biology, the field of animal breeding and genetics will have to adapt to its own needs some new methods developed for other purposes, in addition to contributing approaches specifically designed for livestock problems.

Biology of Systems and Traits

Currently the basic biology (genetics, biochemistry, and physiology) underlying the variability of most traits of interest to animal breeders is poorly understood. This is an obstacle to controlling physiological processes that influence such traits. Molecular genetics will yield abundant novel information on the fundamental regulation of such processes. Here research must aim to provide detailed operational understanding of the pathways involved. Many gene products influence several metabolic pathways, and most metabolic pathways are influenced by several gene products. This makes for very complicated physiological network patterns. In addition, whole sets of genes can be switched on or off via so-called 'epigenetic' mechanisms (DNA methylation, histone acetylation, RNA interference) participating in complex regulatory networks. Such mechanisms are increasingly found to play significant roles in phenotype development and transmission. Control of a single gene may thus cause unwanted side effects when the physiological network around it is not sufficiently understood. Future research must focus on dissecting the genetic basis of traits of relevance to sustainable animal breeding and the interrelationships of these traits.

Whole-Animal Biology and Gene-by-Environment Interactions (GxE)

Understanding individual traits is not enough. What matters is the biology of the whole animal and how an animal's genes interact with its living environment to determine its quality of life and performance. Biological research is already moving towards predictive biology. A first step is to model the various systems that constitute the biology of a cell (creating an e-cell) so as to predict cell responses to environmental change (e.g. altered nutrient supply).

The next step is to build models that describe cell-cell interactions in tissues and finally to build upward from tissues to a whole animal. This is a considerable challenge, but it is undeniably the direction in which biology is heading. High-throughput laboratory methods now make it possible to measure many components of a system in parallel, and these approaches complement the traditional whole-animal research supporting farm animal production. With modern research techniques, scientists will be able to revisit 100 years of animal science with a view to expanding knowledge of all biological mechanisms. Future research must focus on developing an integrated understanding of the lifetime functioning of whole animals and their interactions with the environment. At each step it will be essential to evaluate progress in the light of breeding reality. What breeders need especially is a detailed understanding of relationships between performance, health, welfare, and environmental impact combined with cost-effective, robust, reliable ways to measure traits reflecting these relationships in animal populations.

Population Biology

Future qualitative and quantitative genetic technology will give breeders much control over the genetic makeup of individual animals selected for breeding. In other words, what can be selected with increasing precision is the genome of an individual. Yet population-level effects also deserve consideration for at least three reasons. Firstly, social interactions in groups of animals are associated with behavioural repertoires that are important for animal welfare and for proper functioning of the group: maternal behaviour, dominance and aggression… To the extent that such interactions are linked to production traits, selection could have negative side effects when the physiology of social behaviour is not sufficiently understood.

Secondly, the production potential inherent in an animal's genes is variably expressed according to the nutritional, climatic, infectious, and social environment. This is called environmental sensitivity or phenotypic plasticity. It provides a measure of genotype-environment interactions at the level of an individual animal. Future genetic technology will offer increasing control over environmental sensitivity, and again side effects are likely if interaction mechanisms are not properly understood at population level.

It is important to take into account the dynamics of the environment in which future breeding animals will have to produce. The environment will change in the next twenty years and strategies for the genetic improvement of animal populations must adapt to these changes. Also important is the development of areas such as the improved management of pastures and silvo-pastoral systems for increased overall efficiency in animal production. Research should focus on defining, through population biology, which will be the most efficient genotypes for predictable environments.

Thirdly, disease transmission is perhaps the most crucial population-level issue. Infectious disease involves two (or more) 'actors': host (the farm animal) and pathogen. These two players interact through infection (pathogen to host) and immunity (host to pathogen), and the pathways involved in both processes are under genetic control. Future genetic

Disease Resistance

In most farmed animal species, the balance in the arms race between the 'virulence' of a pathogen (virus, bacterium, or parasite) and the 'defences' of the farm animal host is such that, even with the use of available vaccines, endemic and epidemic disease is a major challenge. It causes poor welfare through ill health, lost food production, and an increased environmental impact per unit output as animals fight disease rather than expending nutrients on food production. It has been estimated that in the order of 17% of production is lost through animal disease in the developed world – and the figure is probably higher in the developing world.

There is now ample evidence that animal species show genetic variation in their resistance to disease or their resilience (the ability to cope with infection). As modern research techniques enable us to better understand the molecular basis of host-pathogen interactions, the potential to select for improved resistance to disease in animal breeding is growing. It might even become possible, via routes such as genetic modification, to introduce complete disease resistance. For example, there are GM cows in the United States that produce in their milk a naturally occurring protein derived from a bacterial species. In early studies, these cows show total resistance to mastitis due to one of the most important mastitis-causing bacterial species.
In addition, the more we learn about genetic variation in hosts and pathogens the better we become at developing effective vaccines. In the future, modelling techniques will allow the co-evolution of hosts and pathogens to be predicted and optimal control strategies derived at the population level.

Improvements in controlling infectious disease have an enormous sustainability-enhancing potential. Reduced disease:
• *improves animal welfare;*
• *improves the production efficiency, reducing the waste of nutrients in the process of fighting disease and hence reducing the environmental footprint per unit output of food;*
• *reduces the risk that animals will be carriers of zoonotic disease;*
• *improves product quality.*

Host-pathogen relationships are complex; there are biological costs to effective disease resistance and there is much yet to be understood. However, relevant research will open up significant new opportunities related to achieving our vision goals of 'safe and healthy food', 'robust and healthy animals', 'sustainable breeding' and 'a competitive Europe'. Research opportunities include:
• *developing selection strategies that exploit the known variation in resistance and resilience to identified diseases;*
• *dissecting genetic variation in the innate and adaptive immune systems;*
• *understanding the molecular biology of host-pathogen interactions and how these change according to variations in the genomes of the two species;*
• *determining the energetic cost of appropriate and inappropriate immune responses to infection;*
• *developing models of the co-evolution of hosts and multiple pathogens.*

technology will provide much knowledge about regulation on each side of such a system, but the connection between the two, i.e. the host-pathogen interaction, is likely to be the crucial element in getting the system under control. Exploring this connection means focusing on epidemiology in relation to pathogen virulence and host resistance. It requires studying the co-evolution of hosts and pathogens. Research exploiting emerging technologies is bound to provide much knowledge on the regulation of the immune system at the individual animal level, but turning this knowledge into operational control will require linking it properly to population-level epidemiology. Future research must focus on understanding how variation in a population affects the overall performance of groups of animals and how changes in biodiversity are likely to influence the control of infectious disease. This will ultimately lead to defining appropriate levels of biodiversity for the long-term sustainability of animal agriculture and aquaculture.

Reproduction Technology

We need research on the reproduction technologies required to underpin breeding and the effective dissemination of genetic improvement to all producers. Artificial insemination is long established in many livestock systems as a central method of animal reproduction with an essential role in breeding programmes and genetic dissemination. More recently, additional techniques have been developed to further improve genetic progress, animal health, and animal welfare, and to disseminate breed improvement. Technologies such as embryo transfer, cloning, and sexing are under development and have had some limited application. Initially, future work on reproduction technologies will aim for a better technical, physiological, and genetic understanding of current and new technologies such as nuclear transfer and cloning for research purposes and semen control of sex determination (e.g. through semen sexing). This will include developing more reliable predictors of semen and embryo quality and studies into the interactions with the environment, nutrition, and infection. Benefits should also stem from research on more reliable indicators of oestrus, conception, and the survival of cryopreserved gametes and embryos. In aquaculture, additional techniques (e.g. for sex determination) and knowledge on the limitations of reproduction are needed.
Future research on cell differentiation may open the way to producing gametes from stem cells. Coupled with predictive biology and statistical techniques such as genome-wide selection, these approaches could make it possible to produce and select multiple generations in the Petri dish. Clearly this entails significant risks as well as potential advantages, so such developments are probably beyond the timescale of our vision.

Reproductive technology research will contribute to safe and wide dissemination of valuable genetic material so as to achieve genetic progress and quick transfer to the production level. Transparency about new technological developments and an open dialogue with society are important in such a sensitive area.

In some livestock systems, such as beef cattle, sheep, goats, horses, buffalo, and most aquaculture species artificial insemination (AI) is still very rare. Reasons for this are many. One of the main reasons is the difficult extensive environment in which these species are usually bred, while AI requires a minimum level of technological input. This applies to a rather large part of livestock production in Europe, and therefore adaptation of the required technology is certainly important.

Biotechnologies

The new cell-based strategies described above have the potential to add to the desired developments in farm animal breeding. More controversial technologies such as genetic modification could be even more powerful, delivering step changes in sustainability in ways unlikely to be possible through conventional selection. For example, there are GM pigs in Canada claimed to have a reduced environmental impact because they have been given a digestive enzyme not naturally present in pigs. This enzyme allows better utilisation of phosphate in the pig's diet, reducing the pollution per unit output. It is debatable whether these pigs will ever be economically viable, but they illustrate the current state of technology. Future research is likely to deliver other GM options, one of the most exciting being the potential to make animals completely resistant to specific viral diseases. If genetic modification (RNA interference) could make chickens resistant to avian influenza and reduce the risk of a human flu pandemic – potentially saving millions of lives – would this be an acceptable use of genetic modification? Despite current public sensitivity, research in the US and Asia is likely to increase pressure on EU agriculture to accommodate novel methods, including the use of nuclear transfer ("cloned") animals for breeding in the pig industry. It is noteworthy in this regard that the US Food and Drug Administration is expected soon to allow products from cloned animals to enter the food chain, with potentially significant implications for international trade, via WTO negotiations for instance. Research in these areas can be part of a medium- and long-term strategy. It can provide information on risks and benefits, enable European society to make informed decisions, and help breeders to define future economic strategies. Research and appropriate communication can also accommodate potential shifts in European public perception in the coming decade.
Genetic modification, research on large-animal embryonic stem cells, and novel methods we have not yet thought of will provide valuable research tools for reducing the number of animals used in research (why do the experiment on an animal if it can be done on a specialised cell line in tissue culture?). Plant breeders

are already 'stacking' multiple genetic modifications in an individual crop. Animal breeding is some years behind, but targeted gene modifications in large animals are required for controlled experimental work. Future research should thus include a focus on: i) basic research in animal embryology and reproduction, ii) deriving farm animal stem cell lines and tools for controlling the differentiation of these lines, and iii) cloning and gene transfer methods.

The need for this type of research stems from Europe's wish to be a knowledge-based economy while taking into account the ethical climate in Europe. It does not stem from current application requests in the animal breeding industry. Yet to adopt a science-based stance, Europe must support the development of new technologies within its borders. We thus strongly support European and national research into new technologies, also in farm animals, as **basic research**, to be conducted in a transparent way. This includes dialogue with stakeholders and society.

Socio-Economic Research

Society and societal attitudes are constantly evolving and are crucial to defining the ethical, legal, and market context in which animals are produced and animal breeding decisions made. Worldwide and even across the EU-25, there is considerable variation among individuals in their attitudes and behaviours towards animal agriculture and aquaculture. It is consequently very difficult for animal breeders to predict future trends. If animal breeding research is to be relevant and animal selection decisions are to be appropriate, biological research must go hand in hand with socio-economic research shedding light on issues such as segmentation among consumers and how beliefs and behaviours interact. What are the range and distribution of consumer attitudes towards foods of animal origin? How do consumers weigh different social considerations (animal welfare, traditional practices, regional distinctiveness...) versus price in their purchase decisions over time? By answering questions such as these, socio-economic research may notably help build models of consumer attitudes towards novel technologies.

Here are some of the topics that socio-economic research should address: the role of animal agriculture in sustainable rural economies and rural environments (for this a holistic (life-cycle) approach is advisable); developing better tools to explore how best to legislate on biotechnology matters and how legislation will affect European competitiveness, consumer health, and food prices; developing effective strategies for communicating information on animal breeding science and technology and for transparency. Lastly, since developments in human genomics are likely to lead to personalised dietary advice on 'good' and 'bad' foods for individuals, an important question is: how will this affect the consumption of animal-derived foods and will this further increase the segmentation of the market?

Animal Science

Equipped with this vast and growing array of extremely powerful technologies, animal breeding is able to address a great many industrial and societal

needs. Yet selective improvement of farm animals must be undertaken in a context of continuing general animal science. As the genetic makeup of farmed animals changes we can expect the nutritional needs of the stock to change as well. This will have an impact on which husbandry practices are most appropriate. Producers with the latest breeding stock also need information and advice on the best available management technologies. Therefore, research along the various lines described in this chapter must be complemented by parallel research in animal production science. Especially important will be redefining the nutritional needs of improved genotypes and adapting management systems to optimise the benefits of selective breeding. The interaction between management and breeding must be acknowledged and will be an important issue in the future.

Technology transfer and training

The research we propose will have a beneficial impact on society only if it is effectively transferred into commercial use. In addition to the participation of industry in as many research projects as possible, these must be accompanied by a coherent technology transfer (TT) programme, a subject that does not always receive the attention it deserves within the research community. Especially when it comes to new technologies based on sciences such as genomics and phenomics, the need for technology transfer to this SME-based sector is obvious. Writing a few papers and speaking at conferences does not constitute effective TT. TT can include simple broadcasting to large audiences, but it also requires more targeted communication (ideally one-to-one and face-to-face) with potential end-users. This activity should also be funded by research funders.

Training is closely linked to TT. In a field as fast moving as animal genetics, there is a constant need for a flow of new scientists skilled in the latest tools into research and industry. Yet we also need new people with the older skills. One of the difficulties industry experiences is a shortage of well-trained quantitative geneticists, especially ones who are also comfortable in molecular genetics. Finally it is important to improve industrial skills in the broader sense. As new tools and technologies emerge there will be a need to improve the knowledge of breeders so that they are receptive to technology transfer and capable of applying these new tools.

Implementing the Vision for 2025: from Innovation to Delivery

As this document highlights, animal breeding and reproduction have an enormous potential to improve our lifestyles and prosperity and to enhance the competitiveness of EU farmers and food producers. In Europe and worldwide, it can also maintain and enhance a sustainable agriculture, a liveable and pleasant countryside, consumer choice, and a secure, safe, and healthy food supply. In order for this future to materialise, the EU and its Member States need to take action now. This is why we are creating a new technology platform to take the first steps towards building a consensus on how to move forward. It will also help to set and coordinate the EU research agenda in the field. The **Sustainable Farm Animal Breeding and Reproduction Technology Platform (FABRE TP)** will be constructed on the following basis:

- Technology transfer and technology translation with emphasis on two-way interactions between industry and research, taking into account the global playing field and the views of society;
- Development and updating of an integrated strategic vision of industrial needs and opportunities in business and research;
- Working with policymakers to ensure a coherent and workable legal framework for the sector's development;
- Involvement of national and international policymakers and research funding organisations to stimulate a coherent yet flexible European research climate in animal breeding and reproduction;
- Transparency and dialogue with society representatives to ensure that research and business are embedded in today's and tomorrow's Europe;
- Awareness of the global context of animal breeding.

The strategic priorities of Europe's main short-, medium-, and long-term animal breeding and reproduction objectives, as laid out in this document, will constitute part of FABRE TP's priorities. Additional priorities may be set in further debate with the various stakeholders. The platform will need to focus on improving the safe exploitation of the genetic diversity of animals in order to:

- produce better-quality, healthy, affordable, diverse food offering consumers in and beyond Europe real options for improving their quality of life;
- strengthen animal agriculture and aquaculture through better animal breeding and reproduction and by interacting more strongly with other fields;
- promote environmental agricultural and aquacultural sustainability, including new applications for pleasure, leisure, or in the medical area;
- enhance the competitiveness of European agriculture and aquaculture organisations.

Main Activities

To meet its strategic priorities, FABRE TP will need to focus on:
- developing and implementing a pertinent long-term research agenda based on identification of the priorities of the sector and of European citizens;
- enhancing the transparency of R&D at the regional, national, and European levels;
- promoting collaborative research efforts and a coherent policy and supportive regulatory environment;
- addressing public concerns and developing societal consensus based on a mutual understanding among all stakeholders.

Management Structure

The FABRE Technology Platform will be managed by a Steering Committee, which will be set up so as to turn the current patchwork of animal breeding and reproduction networks into a coordinated, well-supported business and research network. To do so, a working group and several sub-groups with specialists from science, industry, and society will work out the contents of the Strategic Research Agenda and attract the funding required to implement it.

The Steering Committee will need to link the platform actively with all stakeholders, pooling ideas and fostering support. The Steering Committee will therefore need to be a broad representation of all parties having a stake in this crucial sector, including scientists, industry, consumer and farmer groups, environmental organisations, regulatory bodies, as well as political decision- and policymakers at the EU, national, and regional levels. These partners need to co-operate pragmatically to identify priorities.

What does a time traveller to 2025 find? That the animal breeding organisations have helped to confront some of the major challenges facing Europe and humanity as a whole and has delivered:
- safe and healthy foods from animals;
- robust and healthy animals;
- sustainable animal breeding;
- socially responsible breeding organisations;
- a competitive Europe with affordable food and thriving agricultural and aquacultural businesses;
- a distinctive Europe with a thriving attractive countryside and that celebrates local breeds and food products;
- a Europe that may generate new businesses and prosperity from the application of safe and accepted biotechnologies.

FABRE TP will work closely with other Technology Platforms such as 'Food for Life', 'Plants for the Future', and the 'European Technology Platform for Global Animal Health' (ETPGAH), to capitalise on mutual synergies. In particular, there is significant complementarity between FABRE and ETPGAH in areas such as the genomics of host-pathogen interactions. Joint agreement on priorities for diseases that can be tackled using genetically resistant animals versus those best tackled using vaccines or other strategies would be of mutual benefit to both initiatives.

FABRE TP will be launched on 2 March 2006 at the Salon de l'Agriculture in Paris.

Adopting the Technology Platform

Roadmap and Milestones

The FABRE Technology Platform will promote basic and applied research in animal genetics and reproduction, with emphasis on research implementation, business-oriented research agendas, and strategic public funding in new technologies. It will work within the European legal framework with transparency and dialogue. We recommend the following research milestones on the roadmap towards sustainable animal genetics.

In the Short and Medium Terms (to 2015)

Recommended milestones are:
• to establish coherent animal genetics and reproduction research programmes for the major EU-bred species: ruminants, horses, pigs, poultry, aquaculture species, and species that contribute to the diversity of animal production in Europe;
• to reinforce links between national and European research to build a coherent, comprehensive, and effective research agenda at the European and national levels;
• to promote EU research and development programmes aimed at exploiting knowledge from animal genetics and reproduction to improve sustainable breeding, i.e. breeding that promotes *food safety and public health*, *product quality*, *genetic diversity*, *(biological) efficiency*, *environment, animal health, and animal welfare* in an economically viable way;
• to establish EU-wide public/private partnerships and dialogue with stakeholders (food chain, farmers, and society at large), policymakers, and regulatory bodies to promote sustainable (European) animal breeding and reproduction;
• to establish EU-wide public partnerships and dialogue with stakeholders (business and society), policymakers, and regulatory bodies to explore the development of novel biotechnologies.
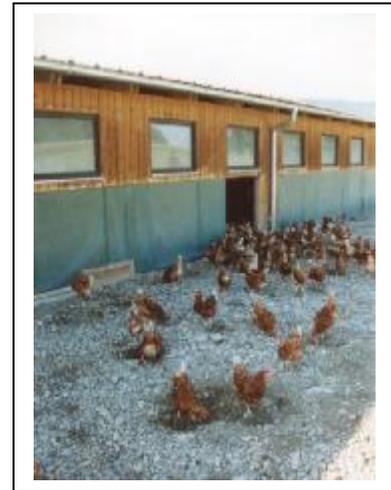
In the Medium and Long Terms (to 2025)

Recommended milestones are:
• to develop a comprehensive knowledge base for all economically and strategically important species bred in the EU and their related genetic resources (this knowledge should span the fields of genetics, animal biology, genomics, and data handling);
• to develop enhanced reproduction tools for preserving the genetic diversity of farm animals;
• to establish public/private partnerships in order to develop robust farm animal breeding that meets the requirements of sustainable production in an environment-friendly manner, while satisfying consumer preferences for healthy and safe food;
• to establish collaborative animal genetics and reproduction programmes with developing countries in order to promote their self-sufficiency, greater sustainability, and competitiveness.

The FABRE Technology Platform will strive to involve all stakeholders in its activities. A major goal will be to translate the strategic priorities defined above into a coherent and dynamic research agenda. The Steering Committee will be managed so as to encourage initiatives in a bottom-up and realistic way. We plan to formulate a strategic agenda by the start of 2007.

FABRE TP will need to exploit available EU instruments and to promote the networking and coordination of national programmes (as exemplified by ERA-NET initiatives). It will also identify and support actions of specific importance at the regional level, complementing these activities with private-public partnerships.

To be successful in the long term, FABRE TP must be transparent and must forge a reasonable consensus at the level of the Steering Committee. Its work must include a critical and objective evaluation of novel developments. Creating a good legal framework for exploiting the results of the research programme will also be crucial.

This platform will help Europe reap the rewards of an invigorated agro-industry delivering a diversity of safe, healthy animal products and bio-products.

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