TWENTY-FIRST CENTURY CHALLENGES FOR GENETIC IMPROVEMENT IN THE LIVESTOCK INDUSTRIES

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SUMMARY
The 21st century challenges for genetic improvement are as they have always been and as they will always be for any century: 1- keep it simple; 2- harness the theory and the practice of selection into the shaping of an ideal that is economically meaningful within the context of the specific production and marketing environments; 3- creatively and effectively combine the available stocks in the shaping of that ideal (i.e., efficient crossbreeding systems); 4- the wise use of available technologies that could foster the accomplishment of that ideal. In the 20th century, the dairy, swine and poultry industries evolved into extremely powerful and efficient breeding machines and production systems. Some costs accompanied the success, and to contain these while maintaining the pace of progress will be one of their main challenges in the next century. In beef cattle breeding, remarkable accomplishments were made throughout the 20th century in the development of adapted types that can survive, reproduce regularly and grow in a multitude of production environments. For the 21st century, the genetic challenges will be to continue to focus on the overall biological and economic efficiency of the total production system, but including in that effort the consideration of those characteristics that determine consumer acceptability of the final product. For this to happen, the development of an economic alignment between the different segments of the industry is one of the most important challenges to be met. The 20th century was notable for a genetic concern about means, while in the 21st century, genetic improvement must accommodate concerns regarding both means and variances. The U.S. sheep industry is in a period of crisis, and their first genetic challenge for the 21st century will have to be the definition of a clear and realistic vision for the role that the industry is to play in the broader context of agricultural and marketing systems. The essence of genetic improvement will remain the same, but change will be a constant, and to be prepared to anticipate and to cope with change will be one of the key challenges for the livestock industries in the 21st century.
Keywords: 21st century, genetic improvement, livestock breeding, beef cattle, future.

INTRODUCTION
In 1983, the American Society of Animal Science published its Diamond Jubilee issue, commemorating seventy-five years of progress, and Gordon Dickerson and Dick Willham wrote: *"In pausing to evaluate progress in quantitative genetics and breeding (...), and especially in attempting to forecast future developments, we become acutely conscious of the very real limitations of personal perspective and of the enormous breadth and depth of this one rather specialized discipline"* (Dickerson and Willham 1983). As we struggled to seriously address the topic, the truth of their statement became evident. Livestock production constitutes a rather

complex system of many interacting components. If the system of reference is carefully bounded, then it may be quite simple to define what *genetic improvement* means in terms of the profitability of a given operation within a defined planning horizon. But, as we proceed to expand the system of reference, and if we consider the many sources of variability that are non-genetic, then the definition of just what constitutes *genetic improvement* is probably beyond consensus. However, if we fail to reach consensus, it is probably meaningless to speak of challenges. Hence, the first and key challenge for *genetic improvement,* is to define what the term means. In 1979, Tom Cartwright commented that *"perhaps even Lush did not perceive the complexity of defining and assessing merit"* (Cartwright 1979). Cartwright (1979) continued: *"this area of defining and assessing merit is the weakest link in the current application of animal breeding theory to real life, at least for some classes of livestock."* Beef cattle breeding, which will be the focus of this paper, certainly suffers from this limitation and, this first challenge must be faced by all of us, if consensus is to be possible. Just as in every animal breeding text book, we shall conveniently ignore this issue and shall assume that we all understand and agree on the meaning of *genetic improvement.* But we alert you to the fact that this is not true and that this is the *key* challenge.

The other great difficulty inherent to the treatment of these types of topics, and which is also often ignored, is who is to benefit from *genetic improvement?* Whose perspective should we adopt in order to address the topic of *challenges?* James (1982) was correct in noting that *"Moav (1973) drew attention to a rather difficult problem in evaluating breeding programs."* The perspective of national interest, that of the established individual breeder, and that of the new investor, are often at odds with each other (Moav 1973). On the brink of the 21st century, we could perhaps add one more perspective, that of the human species. Which of these perspectives should we select in order to address the proposed topic? In other words, whose are these *challenges* that we have been asked to define?

We chose to address the topic from the perspective of those who really make the *genetic improvement.* Those who own the stock. The individual beef cattle breeder who produces seedstock. The *21st century challenges for genetic improvement* are really theirs and not anyone else's. Further, we believe that the future is the past not yet understood. Therefore, in trying to understand the *challenges* for the 21st century, our first question was to ask ourselves if we understood what those *challenges* were for the 20th century. We tried to place ourselves in the year of 1900, possessing the knowledge available at the time, to look into the future that now is already past, exactly as we are doing now for the 21st century, but with the benefit of hindsight. To do that we chose to focus on a particular family of cattle breeders whose successive generations ran a successful operation throughout the entirety of the 20th century. They were successful in the 20th century, and that must mean that they met their challenges. If we succeed in capturing the essence of what were the 20th century challenges for genetic improvement, then we should be better equipped to anticipate the challenges for the 21st century. Perhaps they will be the same. After all, the essence of breeding will not change in the 21st or in any century as long as we continue to deal with the basic reality of biology within an economic context.

THE LOMA BLANCA

The thing that hath been, it is that which shall be;
and that which is done is that which shall be done;
and there is no new thing under the sun.
Ecclesiastes 1:9

South of the Nueces River, in South Texas, there is a white hill which people call the *Loma Blanca.* When it is dry, looking out to the southwest one can see a wide expanse of cracked earth, white from the heavy salt content. The eddies of wind carry sand and salt back and forth across the parched surface, and at night the yelping of the coyotes hidden in the brush breaks the silence (Lasater 1985). At least it was like that in the year of 1900 when Ed C. Lasater rode to its top. He had lost all of his family within a three-year period, and he was still slowly recovering from a debt of $130,000 incurred a few years earlier, when the cattle cycle had once again reached its bottom in 1894 (Lasater 1985). That December night of 1900 he was forty-years-old, a new century lay ahead of him, and he rode to the top of the white hill to envisage the future. He was a rancher and a cattle breeder, his personal and business misfortunes were intertwined, and he had begun to face the challenges he would need to overcome if he were to successfully rebuild his life and make his way in the cattle business of the 20th century.

As he looked to the future, if he could, he would have seen a towheaded boy riding ponies and giggling with delight (Lasater 1985). It was to be his son, Tom. Next he would see two herds of excellent purebred Hereford and Durham Shorthorn cattle grazing the range. The Herefords had pigmentation around their eyes to reduce the risk of cancer eye (Lasater 1985). These were the cattle that he owned and bred at the time, but they were not the cattle of the future. The Shorthorns were big, wide-framed and blood red (Lasater 1985). Both were good purebred cattle herds, among the best there were in Texas, but in many years of less than enough rain they performed very poorly. The cows had a hard time rebreeding, while the calves were very slow to put on weight. Further, both breeds were bothered by the intense heat of the South Texas summer, and by the numerous ticks, flies and mosquitoes of the region, which resulted in unacceptable death rates and other losses of productivity. The cattle were good, but they were not what was needed to make the best of that range (Lasater 1985). To make his purebred cattle really productive he needed to considerably improve the range. But he knew that he could not afford to do this and that if he was going to make it, he needed a low-cost operation. He had already noticed that crosses between the two breeds produced a somewhat more productive calf, and he took advantage of this strategy (Lasater 1985), but it was still not enough. The key was on the cow side, not the calf. He needed a cow that could produce a calf every year, maintain enough condition to rebreed, yet produce sufficient milk to support the growth of an acceptable calf. He needed a cow that could fully utilize the range and that would not be bothered by the heat, ticks or flies.

Earlier that year, in March, across the Atlantic, the editor of the *Reports of the German Botanical Society* had received for publication a manuscript from a professor of botany at the University of Amsterdam reporting the rediscovery of the work of Mendel (Dunn 1965). This did not impact the man on top of the *Loma Blanca.* If he could, he would have been absorbed with the vision of a "grotesque, humped animal" (Lasater 1985). This was a cow that easily took on flesh on short range, was apparently immune to ticks and fever, was heat tolerant, not bothered by flies, that seldom had to be treated for screwworms, and that rapidly multiplied in numbers around the *Loma Blanca* (Lasater 1985). He would have seen that in years when Shorthorn and Hereford yearlings were not in a condition to sell, humped steers were, and that packers found them to dress well and were ready to pay good prices for them (Lasater 1985). He quickly figured that an animal with these attributes could raise the value of South Texas rangelands by $2.00 an acre, and by 1908 he had bought the first set of humped bulls and had initiated a long-range crossbreeding program. He crossed Gir bulls on his Shorthorn cows and bred Nellore and Krishna Valley bulls to a herd of Hereford cows (Lasater 1985). Two years later, T.H. Morgan would publish a scientific review concerning the chromosomal organization of the hereditary material (Dunn 1965), and at about the same time many around the *Loma Blanca* were commenting negatively on the foolish ideas that would lead an otherwise astute cattleman to ruin *"damned good herds"* of purebred cattle (Lasater 1985). Our man, however, noticed neither event since he saw that his crossbred humped cows were returning in net five to ten percent more than the best management could yield from the same ranch stocked with Shorthorn cows (Lasater 1985). In 1914, he purchased an additional 162 Brahman bulls to use on his herd (Lasater 1985).

In 1928, Frederick Griffith, a Medical Officer with the British Ministry of Health, was a bacteriologist studying the infection of mice with *Diplococcus pneumoniae* (Moore 1993). These were the experiments that ultimately led to the discovery of DNA, but our horseback rider would never learn of DNA. In 1930 he would hand over the reigns to his operation to Tom, the towheaded boy (Lasater 1985). His 20th century challenges were to understand the production system and the environment of his ranch and to identify the right cow to match those resources in order to shape a low-cost yet highly productive operation. He had resolved the key piece of the breeding puzzle - the identification of the right cow-type, and the outline of the system of breeding to produce that cow, crossing of breeds. Building on his father's accomplishments, Tom's two main challenges were to be to define exactly the crossbreeding system to be implemented, and to decide the direction in which to shape the cow and its calf, i.e., the selection program.

Tom's 20th century challenges were difficult to resolve. He needed a cow that was about half of the humped type, but to fill the other half he had a choice to make among his Herefords and Shorthorns. Tom studied the performance of the two types of crosses, without resolution. Also, the hybrid cow that he needed did not replace itself and he did not want to keep upgrading toward the zebu. To keep purebred herds was not economically feasible. He could purchase replacements, but besides the fact that no one else was producing this type of cow, except for his neighbors to the east (Lasater 1985), that was really not an option for him. If he could find the right solution for his challenges he would be selling, breeding stock to ranchers, not buying them. After trying different approaches, he found that the Shorthorn cross bulls performed better than the Hereford cross bulls and he bred them to Hereford cross cows. As Tom would explain, *"as soon as the three-way cross calves hit the ground, a blind man could see they were far superior to either of the straight crosses, so we started producing more of the three-way Shorthorn/Hereford/Brahman cross"* (Probandt

1978). Tom decided to breed enough of these three-way crosses to produce a foundation herd with a little less than one-half Brahman blood and the balance being equally divided between Hereford and Shorthorn (Probandt 1978). For about five years he bred a large three-way herd that would allow him to stay free from problems due to inbreeding, and in 1937 he closed the herd and terminated the crossbreeding programs (Probandt 1978). From this point he focused on the improvement of the foundation herd. He had found the right combination of the breeds and had also resolved the problem of how to produce a replacement for the hybrid cow that he needed in the ranges surrounding the *Loma Blanca.* Some thirty-five years before the classic paper of Gordon Dickerson, which would formalize the theoretical approach (Dickerson 1969), Tom had formed a new breed of cattle, a synthetic.

Two of the major challenges inherited from his father Tom had now successfully met. The definition of the exact breed composition for the cow could be considered a detail building on his father's contribution, but the solution of the synthetic breed was a breakthrough with all the trade-marks of a master-breeder. This would again become evident in the shaping of the selection program for the new breed (Lasater 1972), Tom's last remaining challenge. One year before the publication of "Animal Breeding Plans" by the Iowa State University Press (Lush 1937), Tom had already bought a new set of cattle scales and had initiated a systematic program of performance testing on the ranch around the *Loma Blanca* (Probandt 1978). Tom built his program around six essentials: disposition, fertility, weight, conformation, milk production and hardiness (Lasater 1972), but the emphasis was clearly on functional and reproductive efficiency. Any cow that could not wean a good calf every year, beginning as a two-year-old, was culled (Lasater 1972). Sixty-five day breeding seasons, males and females bred at 12 to 14 months, an 80-90% replacement rate from each heifer-crop in order to intensify culling on the cow herd, and any cow without a good calf at weaning or that needed assistance to calve was culled (Lasater 1972). In order to select for milk production, herd sires and heifers were culled on weight at weaning and there had been no "eyeballing" of weight with him since as far back as 1936 (Lasater 1972; Probandt 1978). Noticeably excitable or high-strung animals were systematically eliminated from the herd in order to prevent disposition problems and he also had a "gentling program" at weaning for his replacement cattle. Calves that refused to submit to handling were culled (Lasater 1972). Besides the selection on weaning weight, a post-weaning gain test was conducted under range conditions for bulls up to one-year of age. Females were not selected on weight except at weaning (Lasater 1972). In 1941, seven years before C.R. Henderson would complete his graduate work laying the foundations for mixed model evaluation of EPDs, Tom began selling breeding bulls providing performance data to his customers, in order to emphasize to the industry the importance of growth rate (Probandt 1978). Based on Warwick's (1958) account of the status of the beef industry in 1958, this appears to have been a pioneering initiative on the part of the son of the man of the *Loma Blanca.*

Tom's selection for conformation was an attempt to improve the cutability of his newly formed breed. He culled individuals that were "weak" in the hindquarters or that showed tendencies towards wasty fatty deposits in the brisket, the flank and the top-line (Lasater 1972), but the selection criteria were clearly subjective. Tom also paid special attention to bad legs, pendulous sheaths and weak eyes to emphasize functional efficiency. Selection for hardiness meant that any animal requiring any special care was culled and that medication and vaccinations were kept to a minimum to develop a disease-resistant breed (Lasater 1972). Tom also believed in multiple sire mating to maximize the opportunity for all cows to conceive in their first heat. He feared that single sire mating could result in the favoring of individuals with low inherent fertility, with all its negative implications for a program with a drastic emphasis on female fertility (Lasater 1972). He also firmly believed that a cow should never be culled on age alone, *"the cow of advanced age whose calves are still meeting all production standards is the gem for which everyone is looking. She is introducing effective longevity into the herd"* (Lasater 1972). Tom completely disregarded non-functional traits, such as color and other "breed characteristics," he was also not very fond of keeping records (Lasater 1972).

In 1944, Avery, MacLeod, and McCarty, who for a decade had been following up on the findings of Frederick Griffith, suggested that DNA was the material responsible for heredity (Moore 1993). Four years later, in Denver, Ernie was the Grand Champion Steer. Ernie weighed 895 lbs and his topline hit the showman's beltline (Ritchie 1991). In 1952, A.D. Hershey and Martha Chase worked with bacteriophages and finally proved that DNA was the material of heredity (Moore 1993). About the same time, "snorter" dwarfism took the U.S. purebred beef industry by assault. In 1953, Watson and Crick proposed the double helix structure of DNA and published two very short papers in *Nature* (Moore 1993). Six pages in *Nature*, all that it takes for a Nobel Prize. In 1958, the American Society of Animal Science commemorated fifty years of growth and progress (Briggs 1958). In 1961, the relationship between nucleotides, codons and amino acids was resolved (Moore 1993). In 1969, while Neil Armstrong was taking one small step, Don Good, of Kansas State University, was taking a leap in the show-ring. He selected Conoco, a Charolais-Angus crossbred steer, as the International Grand Champion in Chicago (Ritchie 1991). Conoco was one of the first crossbred winners of a major show in modern times. He weighed 1,250 lbs, graded Choice and yield-graded 2 (Ritchie 1991). In 1975, the International closed its doors. By the early 1980's some champion show steers were taller than their exhibitors (Ritchie 1991). However, neither Ed nor Tom paid much attention to any of this. Tom's cattle never set foot in a show ring nor did he care much for such fads. Further, Tom was busy implementing the selection program he had designed for his breed. In 1949, he patented the Beefmaster name, and five years later, in 1954, the U.S. Department of Agriculture formally recognized the Beefmaster as an American Breed (Probandt 1978). The man on the top of the *Loma Blanca* and his son had accomplished a miracle (Mies 1996). In the harsh ranges of South Texas they had created a cow that could survive, reproduce every year, and deliver a calf that could grow, they had produced a profitable and sustainable production system. They did not swing back and forth like Harlan Ritchie's pendulum (Kester 1992), they did not allow directional change signify progress, they did not get carried away with the power of selection, but instead harnessed it into shaping an ideal born years ago under the mesquite trees of the *Loma Blanca.* They creatively combined breeds in a systematic and planned fashion using a single piece of genetic technology - a scale. These were their challenges for genetic improvement in the 20th century, and they met them all, successfully and masterfully.

A new challenge has developed, but the breeding torch has passed to the grandsons of the man of the *Loma Blanca*. The calf that Ed and Tom Lasater bred must now perform to new specifications in the food market. It is not enough that the calf be efficiently produced. It must be tender, grade, yield a high percentage of boneless closely trimmed retail cuts, grow and convert feed efficiently to have the quality and price to satisfy consumers and yet command a profit for those who ranch the harsh ranges of South Texas. This new challenge must be addressed while not losing any ground in all that has already been accomplished. However, before we focus on the challenges of the 21st century we should not forget the words of the master-breeder: *"Cattle breeding is a relatively simple endeavor. The only difficult part is to keep it simple;" "Truth is both beautiful and profitable"* (Lasater 1972).

NEW TERRITORY

The beef cattle industry is a complex patchwork quilt composed of many somewhat isolated segments, each trying to profit from each other's mistakes (Bill Mies, as interviewed by Andre 1991; Ritchie *et al.* 1996). This segmented structure prevents the flowing of economic signals that could and should promote the impetus for the genetic improvement of many traits that are key to ensure consumer acceptability of the final product, and this has hurt the competitive position of beef in the market place (Mies 1991b; Smith *et al.* 1992; Ritchie *et al.* 1996). A value-based marketing overhaul of the system such that economic signals for carcass yield and meat quality flow consistently and can quickly be translated into action by the different industry segments is in progress (Value Based Marketing Task Force 1990; Engler 1991; Mies 1991b) and one of the grandsons of the man from the *Loma Blanca* is working towards this end (Erramouspe 1995). While this challenge is not genetic *per se*, it is critical for the definition of the genetic challenge to breeders. Jay L. Lush in 1937, and Sewall Wright in 1939, clearly told us how to proceed: clarity of objectives which are supported by rigorous measurements, and the more things that one wants to do the less that one will accomplish in any one of these. However, while everybody agrees on one point - we need consistency, predictability and uniformity of the final meat product and we want it inexpensive while commanding a profit, we have yet to agree on a clear and simple objective. Until this is accomplished, it will be very easy to change things but very difficult to improve anything. Some say that what we need is "young beef," animals that grow quickly and reach optimum slaughter weights fairly young to assure tenderness without the need for marbling. Others say that marbling is the key. Yet others say that marbling is the problem. Some also say that the main challenges in this area have little to do with genetics, but everything to do with nutritional management and pre- and post-slaughter procedures and technologies including food processing and marketing strategies. Some view crossbreeding as resolving the problem, while others seem to be encouraging selection for the ideal carcass. We don't seem to know what we want, and this is the key challenge that we must first address in this area. Harlan Ritchie (1991) has clearly shown us that we may not be that good at defining what improvement is, but we sure are good at changing things. If we can agree on what we want and the economic signals are flowing, the rest will probably be fairly easy. So, the challenges in this area are the goal and the value-based marketing system.

The question of consistency, predictability and uniformity of the final meat product, which was emphasized by the National Beef Quality Audit (Smith *et al.* 1992) and considered by Hale (1992) to be *"the biggest challenge facing the beef cattle industry,"* raises the issue of the management of genetic variances. While in the 20th century genetic improvement was primarily concerned with means, genetic improvement in the 21st century will have to accommodate concerns regarding both means and variances. Some creative thinking in this area would be useful. Breeding strategies utilizing embryo cloning may contribute, but would require careful evaluation. Selection and mating strategies along the lines of those proposed by Kinghorn and Shepherd (1994) could be useful and well designed crossbreeding programs could also make a contribution (Sanders 1990).

THE CHALLENGES

The key 20th century challenges for the genetic improvement of beef cattle were:

1- the understanding of the production system and of the environment;
2- the identification of the right cow-type to match (i.e., to maximize the use of) the resources available in the context of a low-cost operation;
3- the outlining and implementation of efficient breeding plans to produce that cow-type;
4- the shaping of a balanced selection program reflecting a keen awareness of the complex interrelationships among traits and of the relative impact of these on the economics of the production system;
5- the weaving of these components into an operational framework of simplicity and efficiency;
6- the understanding of the difference between change and improvement.

These are also the key challenges for the genetic improvement of beef cattle in the 21st century. And in their essence, the key challenges for the genetic improvement of livestock in general. Some production systems may, of course, encompass the utilization of specialized sire breeds. Selection programs need, of course, to be shaped in ways that reflect the different roles that different breeds may play in production systems.

Reproductive efficiency is the area with the greatest impact on the overall efficiency of beef production (Melton *et al.* 1979; Green 1996) and its improvement was in focus throughout the 20th century and will continue to be among the greatest challenges to beef cattle breeding in the next century. But a greater emphasis on carcass and meat quality traits needs to be part of the genetic improvement schemes of the 21st century. The relative economic value of these traits is presently unclear, and will have to evolve from a marketing system designed to capture signals of consumer preferences and to transmit these signals quickly throughout the production chain and back to the seedstock segments. The development of alliances among the different industry segments (Neumann and Lusby 1986; Eller 1989; Mies 1991a; Erramouspe 1995; Ritchie *et al.* 1996) and the economic alignment of these under a value based marketing system are specific challenges for the 21st century which, if successfully met, will benefit the industry in general.

Measures of the biological and economic efficiency of the total production systems (Moav and Moav 1966; Joandet and Cartwright 1969; Cartwright 1970; Dickerson 1970; Harris 1970; Gregory 1972; Robinson and Orskov 1975; Morris and Wilton 1976; Cartwright 1979; Wilton 1979;

Tess *et al.* 1983; Brascamp *et al.* 1985; Neumann and Lusby 1986; Smith *et al.* 1986; Amer 1994; De Vries and Kanis 1994) also must be kept in focus throughout the 21st century. These are essential to the definition of the breeding objective within the context of specific production and marketing circumstances, resource inputs and management alternatives. Formal frameworks to address these issues and to try to optimize these complex interrelationships, which may include genotype x environment interactions, are available in the form of computer models of production systems (Sanders and Cartwright 1979; Blackburn and Cartwright 1987; Pittroff 1996; Bourdon 1997).

The essence of breeding and genetic improvement will remain the same. But change will also be a constant. Will grain prices escalate to the point that it will significantly affect the structure of many of the livestock industries? Will we be confronted with a future without an abundance of cheap energy? Will there be dramatic technological advances in areas that we cannot even dream of today? Will there be major social and political transformations that will impact our lives and economic activities? We cannot predict these aspects of the future, nor did we view our role as being to make dire predictions. Livestock breeders need to be prepared to anticipate and to cope with change and this is another challenge for the 21st century. Throughout periods of dramatic qualitative change, those who retain flexibility will be among the survivors (Cartwright 1982).

Now that we have addressed the essence of the challenges for genetic improvement in the next century, we will discuss in further detail a number of more specific issues that will be relevant to genetic improvement in the 21st century.

TECHNOLOGIES

The key message concerning breeding technologies for the 21st century is simple - if you do not have a clear idea of the goals that you are pursuing in your breeding program and why, you had better stay away from them. In the 20th century, with little technology, we rapidly moved from Ernie in 1948, a Grand Champion Steer whose topline hit the showman's beltline, to champion show steers in the early 1980's that were taller than their exhibitors (Ritchie 1991). If we indiscriminately employ the powerful array of technologies that will become available in the 21st century, we will be in trouble. On the other hand, those who know what they are doing, who can sense and seize an opportunity and move quickly, will have the potential to carve competitive advantages in short periods of time. It is the fast lane, however, and mistakes in the fast lane usually have very serious consequences.

A more detailed analysis of the breeding technologies of the 21st century will be presented in a companion paper in the Proceedings of the Trangie Industry Day (Taylor *et al.* 1997). Here we simply note that artificial insemination has played an overwhelming role in the dairy industry and is utilized significantly in the beef and swine seedstock industries. Embryo transfer (ET) is also used in the dairy and beef seedstock industries, but at a low level of commitment. Transvaginal ultrasound-guided *ovum* pick-up (Kruip 1994) coupled with *in-vitro* fertilization has the potential to magnify manifold the advantages and minimize or eliminate many of the problems still associated with the classical MOET procedures. *Ovum* pick-up is currently available but needs further development before widespread commercial use at a reasonable cost will be possible. It is likely that this will occur within five to ten years. Embryo sexing is currently commercially available, but its use is limited. To discard half of the collected embryos is not appealing due to the costs involved, but in some situations it could still provide an advantage (De Boer and Van Arendonk 1994). The greatest breakthrough would be sexed semen, but since even Jay L. Lush failed to accomplish this (Lush 1925), the hurdles are high. Embryo splitting is currently available but is not widely used. Unless the objective is to produce identical twins it does not really confer much of an advantage over conventional ET. Embryo cloning currently has significant problems and is not commercially available, but depending on the advances made in embryonic stem cell technology, it may be within ten to fifteen years. Schemes to reduce generation intervals by the collection of prepubertal and fetal oocytes, and their maturation and fertilization *in vitro* (velogenesis) have been outlined (Georges and Massey 1991; Bishop *et al.* 1995). The scheme involving prepubertal oocytes is currently possible and may soon be used in dairy genetic improvement. That involving fetal oocytes is not currently feasible, but may be within ten to fifteen years.

Marker-assisted selection (MAS; Soller 1990) is already in use for a number of qualitative traits (Bishop *et al.* 1995). Marker-based tests for the halothane gene (Webb *et al.* 1994; Wood and Cameron 1994), and for the prolactin-linked milk yield effect reported by Cowan *et al.* (1990) are available and in use. Marker-tests for the Booroola and *callipyge* genes and for resistance to scrapie in sheep may soon be available (Cockett 1996). We anticipate that within five years marker-based tests developed in our Texas A&M "Angleton Project" will be available for carcass and other traits in beef cattle (Taylor *et al.* 1996). Comprehensive schemes of MAS similar to those outlined by Kashi *et al.* (1990) and possibly coupled with embryo technologies will likely be in place within five to ten years in the dairy and swine industries. The poultry industry seems less enthusiastic than the dairy and the swine industries, but some marker-based developments will undoubtedly occur here, while in the beef industry the lack of vertical integration and value based marketing will dictate a slower adoption of the technology. The utility of transgenics will depend on advances in several areas, especially embryonic stem cell and primordial germ cell (Etches and Gibbins 1994) technologies. Developments with a commercial impact may occur within twenty-five years in the poultry and swine industries, perhaps targeting disease resistance or genes coding for enzyme systems with fibrolytic activity (Forsberg *et al.* 1993). Transgenics for functions that imply homeostatic rearrangements are not anticipated at this point. Our understanding of the physiology of production differences needs to be enhanced before these types of ventures can become possible.

Ultrasound technology for the measurement of carcass traits *in vivo* (fat thickness and ribeye area) exists and will play an increasingly valuable role in the breeding programs of the future (Kriese 1996). Technologies to obtain objective measurements of tenderness and intramuscular fat (marbling) are under development and would be very valuable (Bill Mies, as interviewed by Andre 1991), but they need to be practical and inexpensive. Technologies for tenderness do not appear to be imminent, but for intramuscular fat they may soon be available (Kriese 1996).

EPDs

The relevance of mixed model genetic evaluation procedures and their overwhelming contribution to genetic improvement in many breeding systems is beyond question. The statistical development of best linear unbiased prediction (BLUP) of breeding values (Henderson 1984) has been one of the most outstanding contributions to animal breeding research in the 20th century. In breeding systems characterized by a fairly uniform environment (in the broad sense), with fairly simple definitions of aggregate net merit, and with a high degree of connectedness among herds, EPDs have become an invaluable breeding tool largely responsible for the formidable genetic progress that has been achieved. This has been the case in dairy cattle, but not in beef cattle or sheep breeding (Ponzoni 1988; Johnson and Garrick 1990; Banks 1992; Barwick *et al.* 1992; De Rose 1992; Barwick *et al.* 1994; Fries 1994; Menissier 1994; Newman and Ponzoni 1994). Perhaps no one has defined the problem better than Rick Bourdon of Colorado State University (Bourdon 1997). The economic performance of beef production systems depends on many traits and on their complex interactions among themselves and with a multitude of environmental and management variables. EPDs are single trait selection tools which are statistically sophisticated and make a very nice marketing tool, but just how they should best be used in a complex breeding system like beef cattle production is open to opinion. *"The problem is not that EPDs are calculated incorrectly or with insufficient accuracy. The problem is that these predictions are presented without context. There is no easily accessible, objective way for beef and sheep breeders to use these predictions intelligently."* Further: *"It is tempting for those of us in academic animal breeding to sit back, pat ourselves on the back for a job well done, and conclude that genetic evaluation has reached a mature stage and the only tasks left consist of a little refinement here and there. I think, however, that genetic evaluation is anything but mature. In fact, I would say that our current genetic evaluation technology is primitive"* (Bourdon 1997). We agree. Bourdon (1997) introduced a general bioeconomic simulation framework to examine the effects of multiple-trait selection on the economics of commercial production, and which explains to producers how the use of alternative genotypes affects production, costs and profit. The goal is to assist in the definition of the breeding objective and hence identify near-optimal genotypes to support sire selection by simulation procedures. This has been an important and timely contribution which leads the way vis-à-vis the challenges to be faced in this area in the 21st century (Menissier 1994). The development of sound procedures for across breed genetic evaluation (Benyshek *et al.* 1994) and for carcass traits (Green 1996) will also be important contributions.

OTHER INDUSTRIES

Throughout the 20th century the dairy, swine and poultry industries evolved into highly efficient and powerful breeding machines and production systems which now operate extremely efficiently in many respects. This was achieved with costs whose containment, along with the simultaneous improvement of efficiency, will be part of the challenges for these industries in the 21st century. Reproductive and metabolic disorders and mastitis in dairy cattle, and leg disorders, sudden death syndrome and ascites in poultry (Pingel 1994), are examples of these types of situations. As pathogenic agents evolve rapidly, breeding for disease resistance will continue to be a key challenge to the poultry industry. Technological developments and new trends in the industrial processing of eggs (liquid eggs) will cause the shifting of selection emphasis among traits. The improvement of carcass and meat quality traits will be in focus in the swine industry. The extension of BLUP models to include nonadditive genetic effects for some traits would probably be useful in some of these industries. Minimum-risk breeding strategies to restrict rates of inbreeding and variance of the selection response (Meuwissen and Woolliams 1994) will probably become more important in dairy breeding as a result of the dramatic genetic gain that has been accomplished at the expense of genetic variability (Meuwissen and Woolliams 1994). Globalization of dairy breeding will increase the demand for effective international genetic evaluation procedures (Banos 1994). Due to their intensive nature, all three industries will face challenges posed by animal welfare and environmental concerns (Steinfeld *et al.* 1996). Some of these concerns may be addressed from a genetic perspective (Muir 1994; Pittroff 1996), but most will probably not pose direct genetic challenges to these industries.

In 1942, there were over 56 million head of sheep in the U.S., about the same number as in 1844, and there were but a few, relatively minor, fluctuations in the population during that 100 year-period (Terrill 1958). By 1958, the number had declined to 31 million, and since 1960 the decline has been almost continuous and rapid (Terrill 1958; Parker and Pope 1983). In 1983, there were about 12 million (Parker and Pope 1983), and last year about 6 million sheep in the U.S. (Thomas 1996). Between 1961 and 1983, the *per-capita* consumption of lamb and mutton in the U.S. decreased 70%, from 2.4 to .7 kg/*capita* (Parker and Pope 1983). The lamb market-share is now less than 1% of the total meat consumed in the U.S. (Bogue 1996). Terrill (1958) did not attribute much relevance to the 25 million decline in sheep numbers between 1942 and 1958. However, Parker and Pope (1983) indicated that by the early 1960's people were concerned, conferences and studies were held, and it was concluded that "the industry was at an important crossroads relative to its future." If this was accurate, the industry seems to have stalled there. Clinton Hodges, a Rambouillet breeder from Sterling City, Texas, recently stated that *"many breeders are still without any idea of the sheep they need to be producing or where they are going within the industry"* (Hodges 1996). Hence, the *key* 21st century genetic challenge for the U.S. sheep industry appears to be the definition of a realistic and clear vision for the role that sheep can play within the present context of agricultural and marketing circumstances.

MEGA-TRENDS

Projections of the International Food Policy Research Institute to the year 2020 (Rosegrant *et al.* 1995) suggest a fairly stable scenario worldwide with no qualitative departures from current circumstances. There will be an increase in food demand and production due to increased population and continued economic growth and development, and a period of vibrant global trade is anticipated with the East Asian countries being major importers of livestock products. World trade in meat is expected to nearly triple, with the greatest increase occurring in poultry. International beef trade is expected to increase 187% (Rosegrant *et al.* 1995). The greatest beneficiaries of this trade will be the developed economies and particularly the United States, which is expected to rapidly expand its agricultural exports. However, many problems in poor countries, including malnutrition and food scarcity, are likely to remain (Rosegrant *et al.* 1995). Steinfeld *et al.* (1996) presented an excellent summary of global issues which will likely impact livestock production systems throughout the 21st century, including the growth of the human population and its implications for the sustainability of the natural resource base of soil, water, air and biodiversity. While some of these issues will pose difficult and complex challenges to the intensive livestock industries, these challenges will generally not be genetic, although emphasis on some new traits and functions may occasionally be appropriate, e.g., "minimum emission of contaminants per unit offtake produced" (Pittroff 1996). The odor problem in swine production is another example of a situation that could perhaps be amenable to genetic analysis and improvement.

CROSSBREEDING: INTO THE NEW MILLENIUM

The story of the Lasaters throughout the 20th century provides a powerful example of the utilization of crossbreeding systems in livestock breeding. The stage has been set for a proliferation of crossbreeding in the 21st century. Particularly in the tropics and subtropics, well designed crossbreeding systems could provide the greatest opportunity for genetic improvement of large ruminants (Davis and Arthur 1994) and have a major impact on productivity (Francis 1970; Plasse 1988; Sanders 1988; Frisch 1992; Davis and Arthur 1994; Sundstrom *et al.* 1994). Gordon Dickerson (1969) laid the theoretical foundations and provided new emphasis to the utilization of synthetic breeds in the modern era of efficient livestock crossbreeding systems. This led to the critical Germ Plasm Evaluation (GPE) and Germ Plasm Utilization (GPU) Programs conducted at the U.S. Meat Animal Research Center (MARC) at Clay Center, Nebraska (Gregory *et al.* 1995). These programs represent a major landmark of animal breeding research in the 20th century. The GPU focused on the evaluation of the role of composite (synthetic) populations in breeding systems, and led to the conclusion that: "*composite populations (breeds) offer an alternative breeding system that is generally competitive with crossbreeding for using heterosis and is easier to manage regardless of size of herd. Composite populations (breeds) offer a procedure that is more effective than continuous crossbreeding for using genetic differences among breeds to achieve and maintain optimum performance levels for major bioeconomic traits on a continuing basis. This includes traits such as: a) growth rate and size, b) composition of gain, c) milk production, d) climatic and nutritive adaptability, and e) age at puberty. No increase in genetic variation was observed in composite populations relative to contributing purebreds. Composite populations (breeds) have a high degree of uniformity both within and between generations*" (Gregory *et al.* 1995). Some of these points were already apparent in the program of the Lasaters sixty years ago, but the GPE and GPU programs collected a vast amount of valuable data and set the scientific stage for a proliferation of systematic crossbreeding programs of which several excellent examples currently exist (Stewart-Smith 1988a; 1988b).

Like Sanders (1990) and Dikeman (1994), Gregory *et al.* (1995) concluded that well-designed crossbreeding programs are probably the most logical and effective approach to adequately tackle some of the issues related to the genetic improvement of carcass and meat quality traits. One of MARC's most interesting results (Koch *et al.* 1990), relates to the superior performance of *Bos indicus* x *Bos taurus* cross cows for maternal traits and cow efficiency. Even in a temperate climate with harsh winters, these cattle outperformed *Bos taurus* x *Bos taurus* cross cows for these traits (Koch *et al.* 1990). This indicates the high levels of heterosis available from *Bos indicus* x *Bos taurus* crosses, which emphasizes the potential impact of crossbreeding systems in tropical and subtropical regions (Francis 1970; Plasse 1988; Sanders 1988; Frisch 1992; Davis and Arthur 1994; Sundstrom *et al.* 1994), especially considering the availability of tropically adapted *Bos taurus* breeds such as the Latin American "criollo" and the African Sanga types. This leads to the most important unanswered research question in this area; that of the levels of heterosis retention to be expected in advanced generations of these crosses. The answer to this question is key to guiding the development of efficient crossbreeding systems in the tropics. The GPU program did not include composite populations involving *Bos indicus*, and there is a fear that the high levels of heterosis retention in advanced generations of *Bos taurus* x *Bos taurus* crosses (Gregory *et al.* 1995) will not occur for *Bos indicus* x *Bos taurus* crosses. A major project is currently under way at Texas A&M University to address this issue (Sanders and Lunt 1996). Another important question, still unresolved, purports to the exact genetic mechanisms underlying the large reciprocal cross-effects observed in these types of wide crosses (Thallman *et al.* 1992; Rohrer *et al.* 1994), one more challenge for the future.

The *key* 21st century challenge in the area of crossbreeding will be to capitalize on the impetus provided by GPE and GPU (Gregory *et al.* 1995) and other projects (Sanders and Lunt 1996), to effectively utilize heterosis, complementarity and additive breed effects. Heterosis has the greatest impact on fertility, maternal traits and calf survival, and these traits have the greatest impact on the efficiency of beef cattle production systems. The opportunity seems clear and considerable. Since the disease transmission potential of embryos is limited (Singh 1988), we may now view the world as a single breeding pool, which creates unforeseen opportunities. Given the very large number of diverse breeds that exist and that effective, well organized long-term breeding strategies are in demand to assure that the best be made of the opportunities provided by this genetic variability, and that conservation of these breed resources can be accomplished (Dickerson and Willham 1983; Hammond 1994), we suggest that their utilization in the new millenium be guided by:

1- the organization of breeds into major phylogenetic groups, e.g.: British, Continental European, Zebu, Sanga, etc., and the definition and implementation of adequate within-breed selection and conservation programs;
2- the definition and implementation of research projects along the lines of the GPE which would sequentially focus on pairs of the major groups, and which should be conducted in biomes representing existing production systems, with the objective of identifying the individual breeds yielding the highest levels of heterosis, particularly in cow traits. Breeding systems should utilize these in commercial production where appropriate;
3- the best two or three breeds (with respect to crossbred performance) within each major group, should be combined to form a number of composite populations, within each group, to support commercial production systems in more limiting environments. Selection programs should be implemented within these composites;
4- composites between major groups should then be formed from the within-group composites and appropriate selection programs within these new composites implemented.

Of course, corn breeders could implement this modified reciprocal recurrent selection scheme in 20 years, but for livestock breeders the 21st century will probably not be a sufficient time frame. Theory for the combination of within-breed and crossbred performance in selection programs has recently been proposed (Van der Werf *et al.* 1994).

Finally, we ask: will the biological basis of heterosis be unravelled in the 21st century? Will the Mendelian model be sufficient to accomodate it? Realistically, this may be a challenge better suited for resolution by plant breeders, nevertheless, its resolution is likely to lead to exciting new opportunities in breeding and production systems.

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