“Animal biotechnologies and agricultural sustainability”

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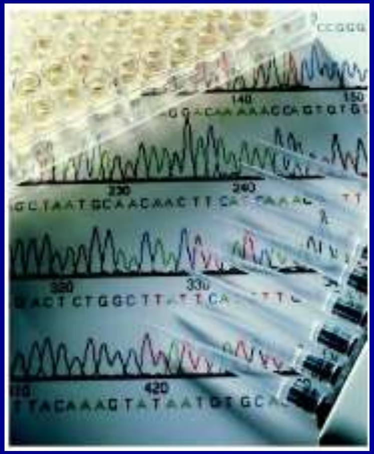
Overview of "Animal biotechnologies and agricultural sustainability" chapter

- Introduction and background including the projected growth "Livestock Revolution"
- Definition of Animal Biotechnology
- Potential Benefits and Risks associated with:
  - Genetic Engineering (GE)
  - Cloning
  - Genomic Selection
  - Functional Genomics
  - RNAi
  - Other technologies (GE rumen micoflora, rBST)



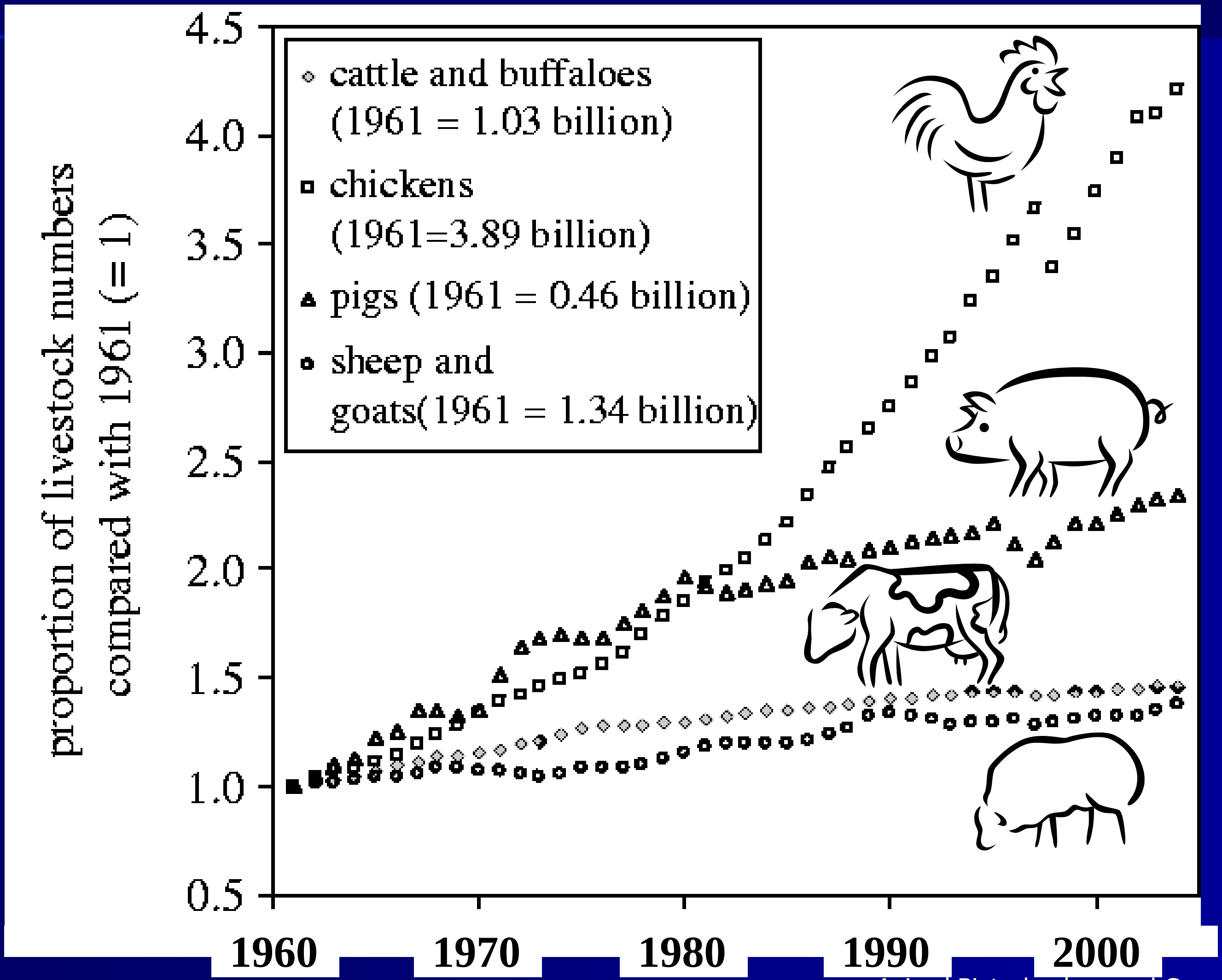
What is Sustainability?

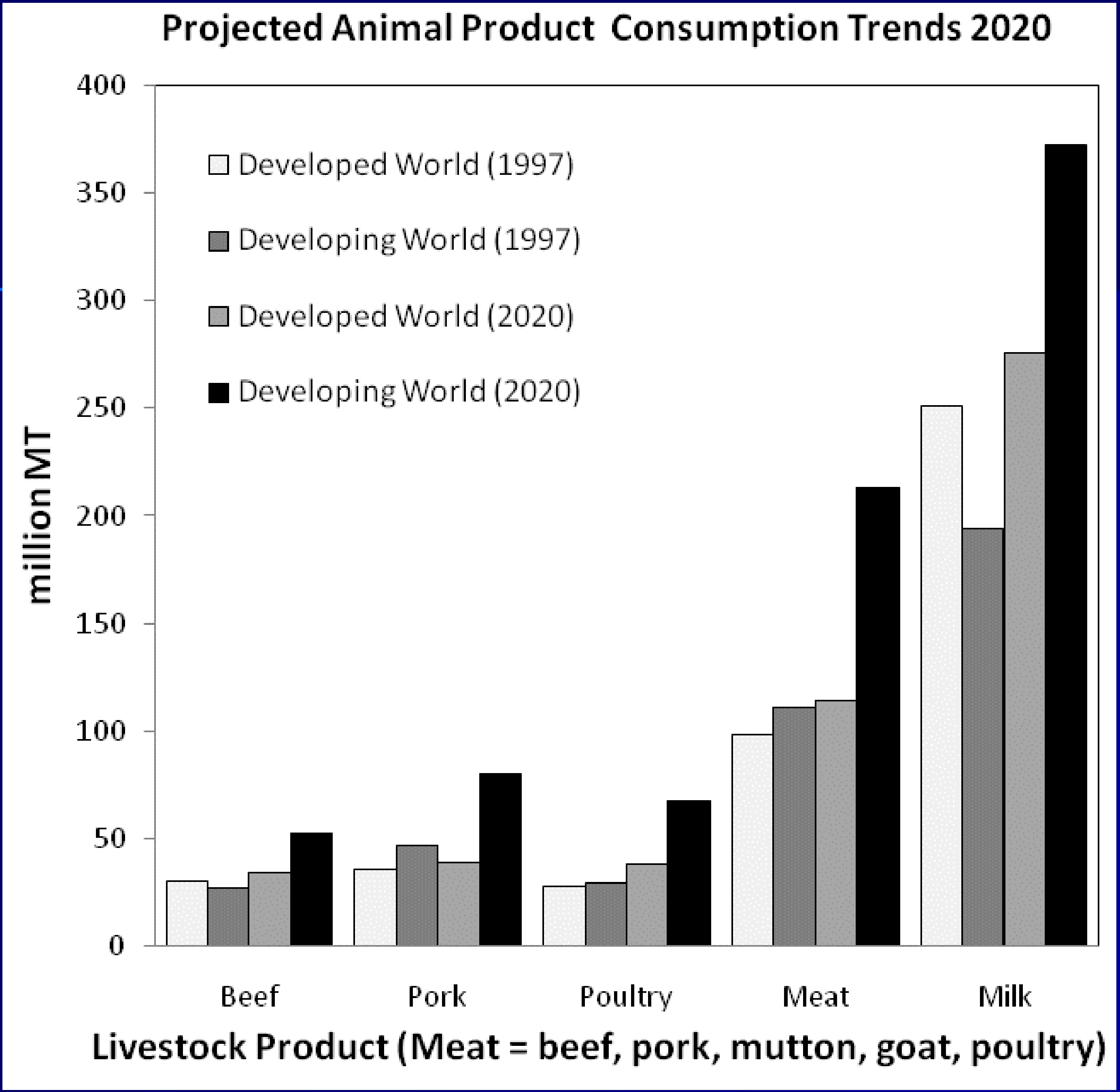
Quantity (1,000 MT) and percent of global livestock products produced by the three major production systems (Seré and Steinfeld, 1996).

Product	Grazing		Mixed crop-livestock		Industrial	
	1,000 MT	%	1,000 MT	%	1,000 MT	%
Beef and veal	12,289	23.4	34,249	65.1	6,055	11.5
Buffalo	0	0.0	2,652	100	0	0.0
Sheep and goat	2,981	30.0	6,860	69.0	100	1.0
Pig meat	685	1.0	42,821	59.8	28,163	39.3
Poultry meat	796	1.8	10,469	24.2	31,967	73.9
Eggs	524	1.3	12,289	30.8	27,071	67.9
Dairy milk	38,775	8.2	434,332	91.8[a]	0	0.0

[a]The authors list intensive dairy systems as part of mixed-crop livestock systems, which in general they are. However, some modern dairy production could also be classified as industrial.

Proportional increase in world head of livestock 1961-2004; data from FAO (2005)




Projected Animal Product Consumption Trends 2020
Developed World (1997)
Developing World (1997)
Developed World (2020)
Developing World (2020)
million MT
400
350
300
250
200
150
100
50
0
Beef
Pork
Poultry
Meat
Milk
Livestock Product (Meat = beef, pork, mutton, goat, poultry)

Animal breeders have been genetically-modifying animals for centuries






Animal biotechnology: The application of science and engineering to animals.

- Artificial selection (breeding programs)
- Artificial Insemination
- Using DNA information for the marker-assisted selection of superior animals
- Genetic engineering
- Cloning
- Genomic selection
- Functional genomics
- RNAi

Breeders can influence the rate of genetic gain by altering components of the following equation:

ΔG = ***intensity of selection X***

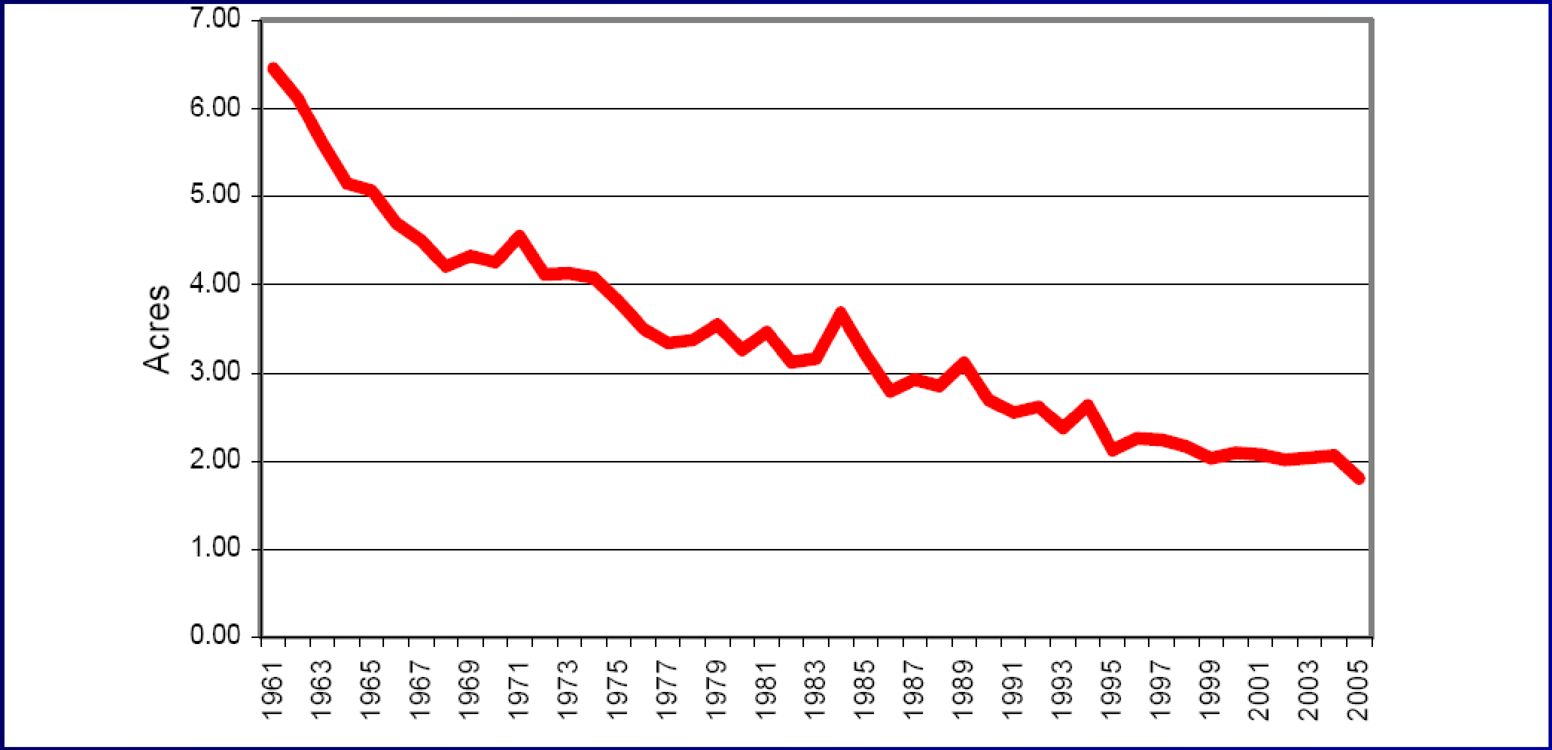
accuracy of selection X

(√genetic variance in population /

generation interval)

As a result of selective breeding and increasing crop yields, in 2005 the amount of crop land required to produce one ton of meat and poultry was 1/3 that required in the 1960s

U.S. Feed Grain/Soybean Acres Used Per Ton of Meat and Poultry Production



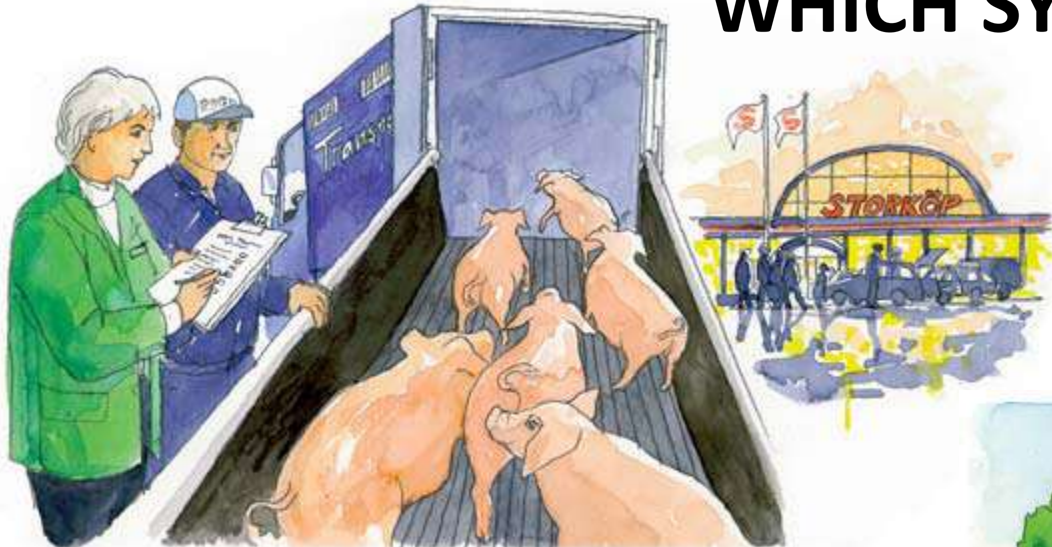
EXTANT APPLICATIONS	Species	Gene	Approach
PRODUCTIVITY			
Enhanced growth rate	Many fish species	Growth Hormone	Transgene overexpression
Enhanced milk production	Swine	α-lactalbumin	Transgene overexpression
Enhanced growth rate	Swine	Growth hormone	Transgene overexpression
Enhanced growth rate	Swine	Insulin-like-growth factor	Transgene overexpression
DISEASE RESISTANCE			
BSE resistance	Cattle	Prion	Knockout
Mastitis resistance	Cattle	Lysostaphin, Lactoferrin	Transgene overexpression
BSE resistance	Goat	Prion	RNAi transgene
Visna virus resistance	Sheep	Visna virus envelope gene	Transgene overexpression
Mastitis resistance	Goats	Lysozyme	Transgene overexpression
GCH virus resistance	Grass Carp	Lactoferrin	Transgene overexpression
Bacterial resistance	Channel Catfish	Cecropin B gene	Transgene overexpression
ENVIRONMENTAL			
Decreased P in manure	Swine	Phytase	Transgene overexpression
PRODUCT QUALITY			
Increased ω-3 fatty acids in meat	Swine	n-3 fatty acid desaturase	Clone/Transgene overexpression
Increase cheese yield from milk	Cattle	β-casein, κ-casein	Clone/Transgene overexpression
Monounsaturated fatty acids in milk	Goat	Stearoyl-CoA desaturase	Transgene overexpression

Enviropig^{TM} (Low-phosphorus manure) http://www.uoguelph.ca/enviropig/

"reduces fecal phosphorus output by up to 75%"

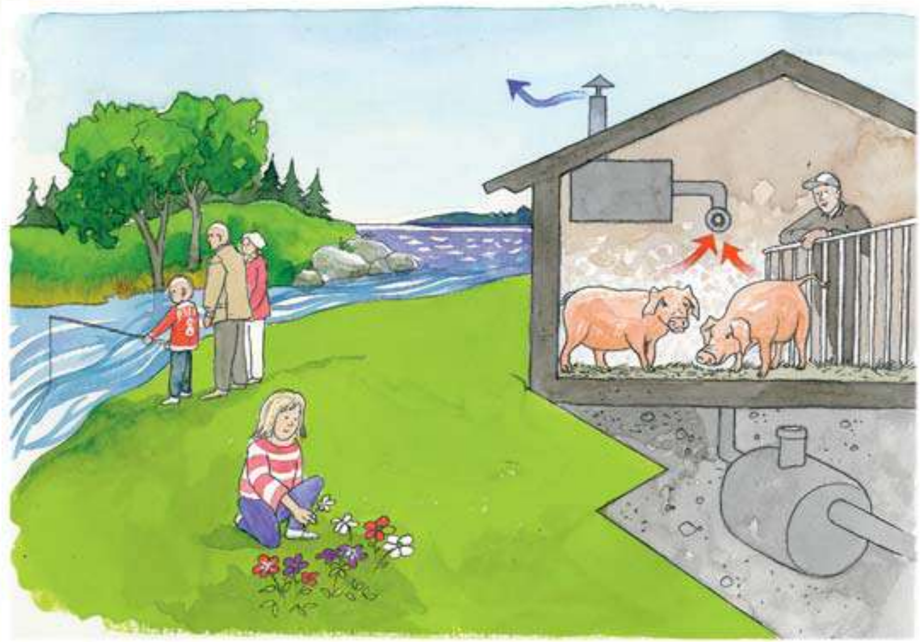
(Golovan et al. 2001. Nature Biotechnology)

WHICH SYSTEM IS SUSTAINABLE?



1. Improved product quality and safety.

2. Improved animal welfare and natural behavior.



3. Decreased impact on the environment and efficient use of natural resources.

Illustrations from Stern,S., Sonesson,U., Gunnarsson,S., Oborn,I., Kumm,K.I., & Nybrant,T. Sustainable development of food production: A case study on scenarios for pig production. *Ambio* 34, 402-407 (2005).

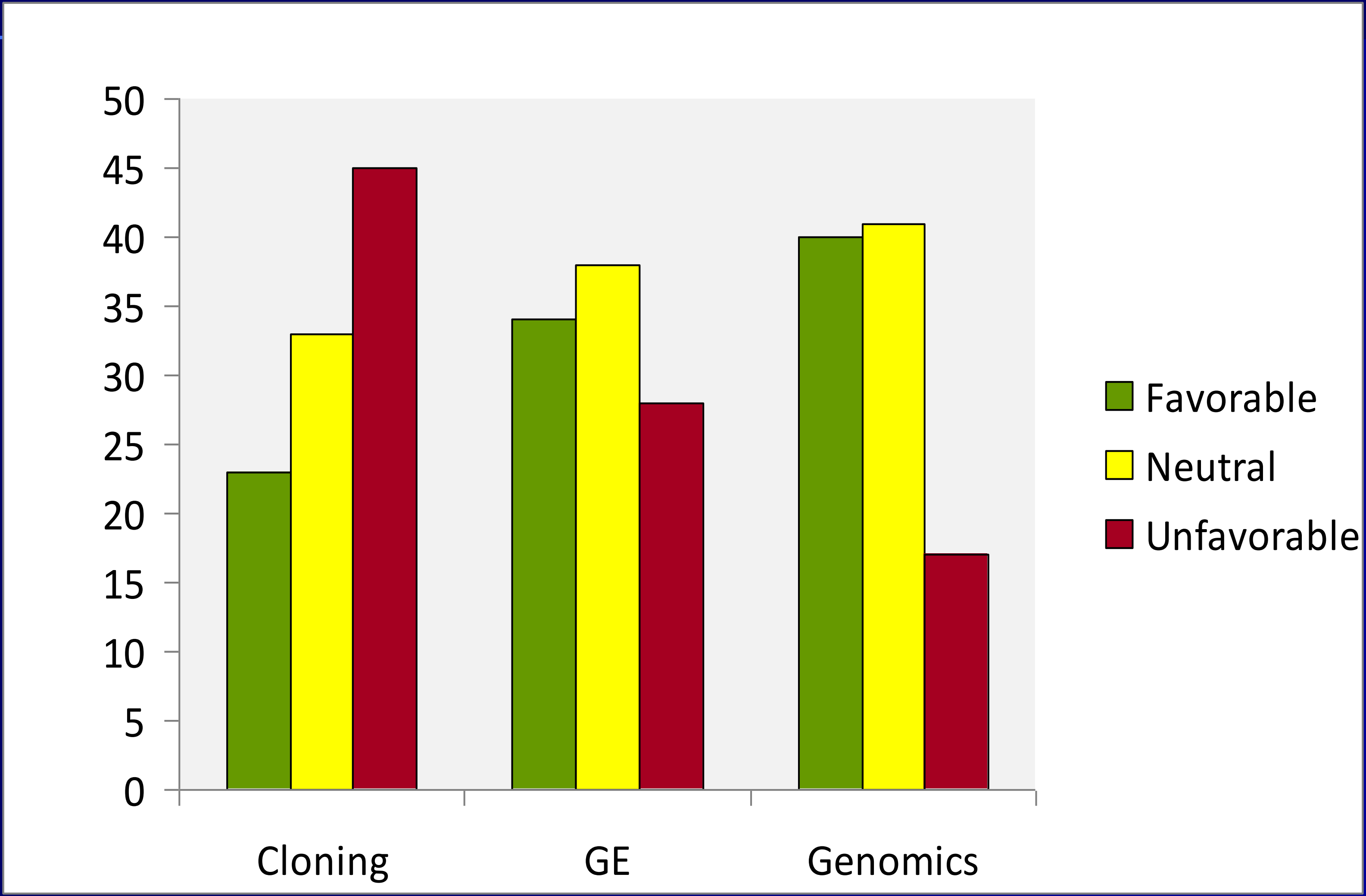
Envisioned GE livestock applications

ENVISIONED APPICATIONS	Species	Gene	Proposed Approach
Increased lean-muscle growth	Cattle	Myostatin	RNAi /Knockout
Increased post-natal growth	Various	Socs2	RNAi /Knockout
Enhanced mammary gland development	Various	Socs1	RNAi /Knockout
Suppressing infectious pathogens	**Various**	**RNA viruses (eg . foot and mouth, fowl plague, swine fever)**	**RNAi**
Coronavirus-resistance	Swine	Aminopeptidase N	RNAi /Knockout
Avian flu resistance	Poultry	Avian influenza	RNAi
Low lactose milk	Cattle	Lactase	Transgene overexpression
Low lactose milk	Cattle	α-lactalbumin	RNAi /Knockout
Increased ovulation rate	Sheep	GDF9, BMP15, ALK6/BMPR1B	RNAi /Knockout
High omega-3 fatty acid milk	Cattle	n-3 and n-6 fatty acid desaturase	Transgene overexpression
Resistance to Brucellosis	Cattle	NRAMP1	Transgene overexpression
Decreased P in manure	Poultry	MINPP	Transgene overexpression
Decreased P in manure	Poultry	Phytase	Transgene overexpression

2001 Foot & Mouth Outbreak in UK

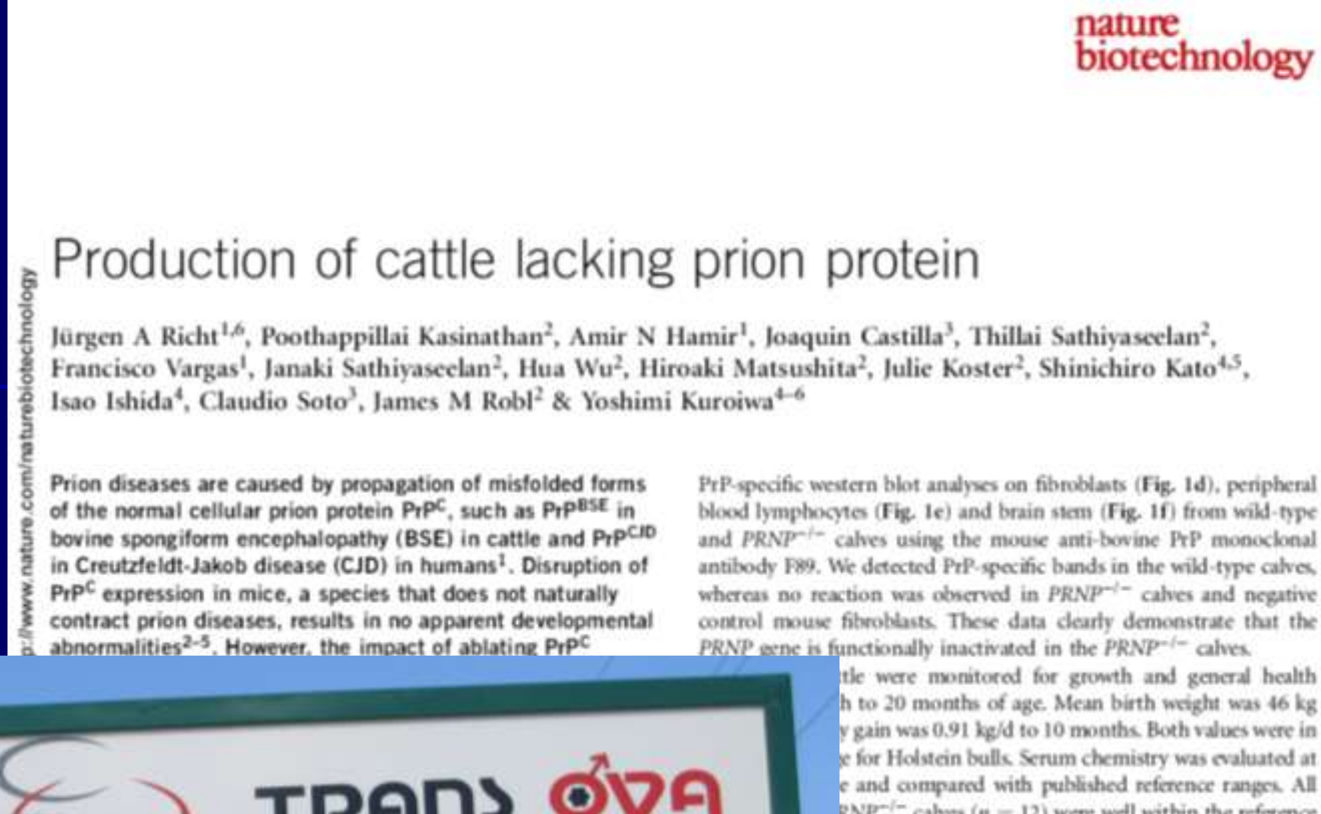
- Millions of animals slaughtered from 10,000 farms
- $ 3.5 to $ 6 billion lost, Numerous producer suicides

Public Attitudes Towards Specific "Animal Biotechnologies" (IFIC, 2008)



http://www.ific.org/research/biotechres.cfm

"The public opposes the cloning of animals"


nature biotechnology

Production of cattle lacking prion protein

Jürgen A Richt[1,6], Poothappillai Kasinathan[2], Amir N Hamir[1], Joaquin Castilla[3], Thillai Sathiyaseelan[2], Francisco Vargas[1], Janaki Sathiyaseelan[2], Hua Wu[2], Hiroaki Matsushita[2], Julie Koster[2], Shinichiro Kato[4,5], Isao Ishida[4], Claudio Soto[3], James M Robl[2] & Yoshimi Kuroiwa[4–6]

p://www.nature.com/naturebiotechnology

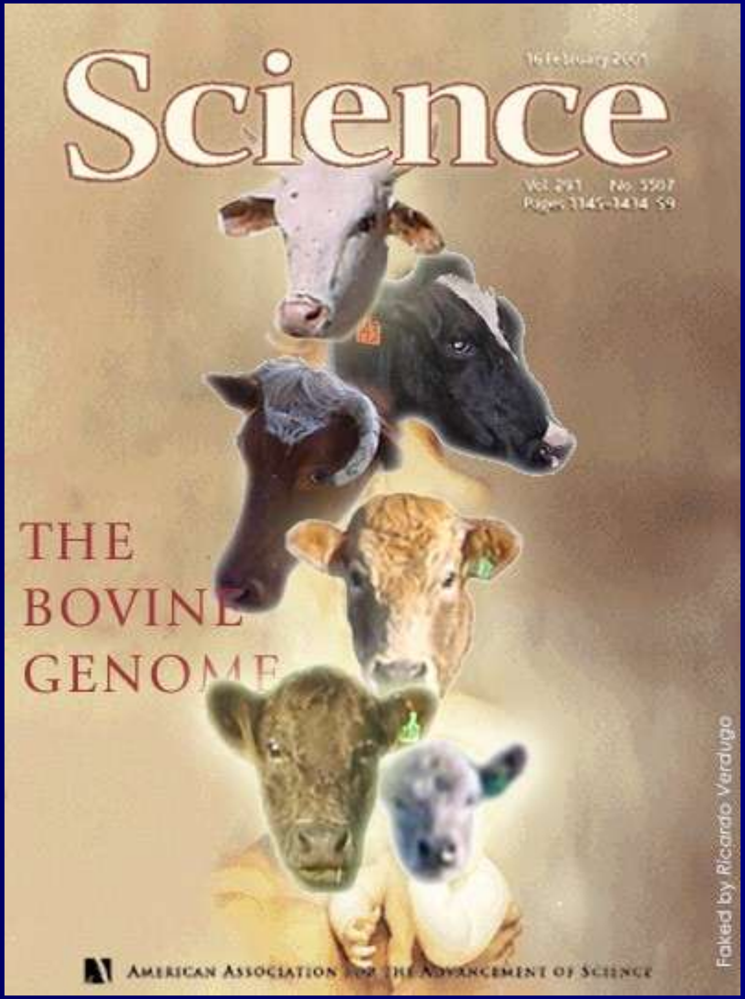
Prion diseases are caused by propagation of misfolded forms of the normal cellular prion protein PrP^C, such as PrP^{BSE} in bovine spongiform encephalopathy (BSE) in cattle and PrP^{CJD} in Creutzfeldt-Jakob disease (CJD) in humans[1]. Disruption of PrP^C expression in mice, a species that does not naturally contract prion diseases, results in no apparent developmental abnormalities[2–5]. However, the impact of ablating PrP^C

PrP-specific western blot analyses on fibroblasts (**Fig. 1d**), peripheral blood lymphocytes (**Fig. 1e**) and brain stem (**Fig. 1f**) from wild-type and *PRNP*$^{-/-}$ calves using the mouse anti-bovine PrP monoclonal antibody F89. We detected PrP-specific bands in the wild-type calves, whereas no reaction was observed in *PRNP*$^{-/-}$ calves and negative control mouse fibroblasts. These data clearly demonstrate that the *PRNP* gene is functionally inactivated in the *PRNP*$^{-/-}$ calves.

...tle were monitored for growth and general health ...h to 20 months of age. Mean birth weight was 46 kg ...y gain was 0.91 kg/d to 10 months. Both values were in ...e for Holstein bulls. Serum chemistry was evaluated at ...e and compared with published reference ranges. All

http://www.hematech.com

High-throughput SNP genotyping on 50,000 SNP CHIP (50K Chip)



The sequencing of the bovine genome allowed for the development of a 50,000 SNP CHIP

Genomic Selection

"There is no doubt that whole genome-enabled selection has the potential for being the most revolutionary technology since artificial insemination and performance-based index selection to change the nature of livestock improvement in the foreseeable future"

Dorian Garrick, Lush Chair in Animal Breeding & Genetics, Iowa State University

Natural genetic variation

Is animal biotechnology risky?

Excessive caution does not necessarily remove the risk of future catastrophes. It is possible that "**playing it safe**" by abandoning research and development in animal biotechnology might deny us a technique or products which could prevent an environmental or public health disaster in fifty years time, or could prove invaluable in the treatment of some disease.

Would there be general acceptance of transgenic technology if it could be applied to engineering resistance to influenza in poultry and therefore lessen the risk of an influenza epidemic, such as the one in 1918 that killed more than 20 million people?

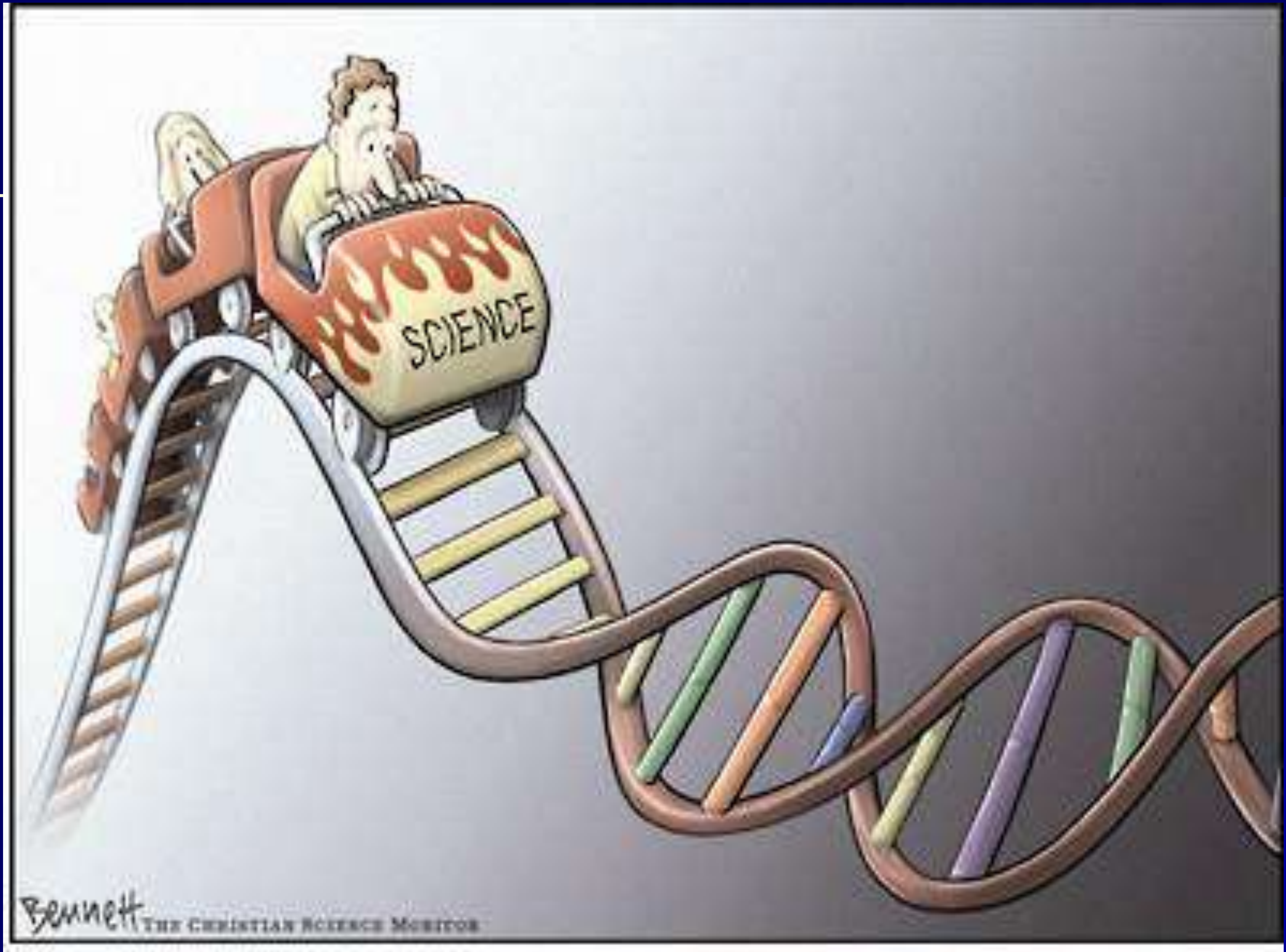
Clark,J. & Whitelaw,B. 2003. A future for transgenic livestock. *Nat. Rev. Genet.* **4**, 825-833

“The idea of agricultural sustainability does not mean ruling out any technologies or practices on ideological grounds. If a technology works to improve productivity for farmers, and does not cause undue harm to the environment, then it is likely to have some sustainability benefits.”

The use of rBST:

- markedly improved the efficiency of milk production, AND ALSO
- decreased eutrophication, acidification, greenhouse gas emissions, and fossil fuel use (Capper et al., 2008).

This example emphasizes the need to weigh decisions to restrict producer access to a high yield technology or genetic resource that improves productive efficiency against the potential negative impact such decisions may have on achieving environmental sustainability goals.


SCIENCE
Bennett
THE CHRISTIAN SCIENCE MONITOR