What role will animal biotechnology play in feeding the world?

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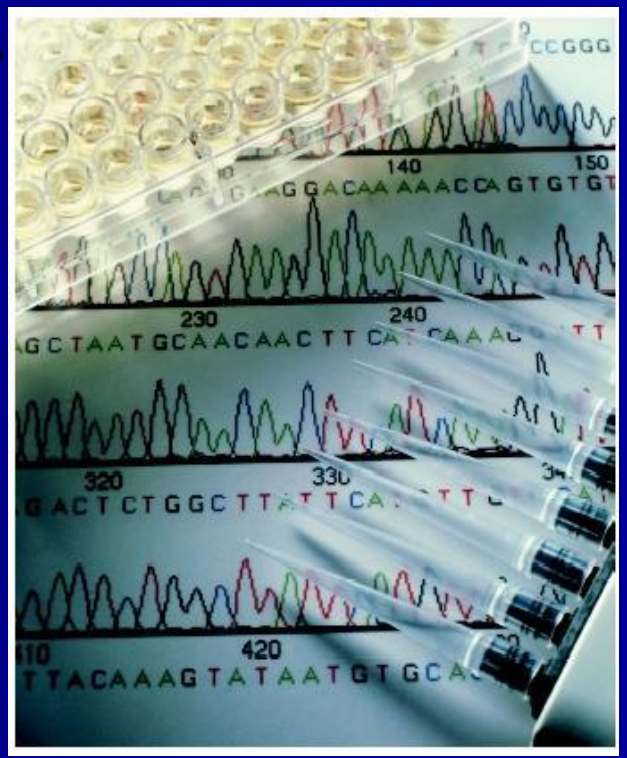


"The mission of the animal genomics and biotechnology extension program is to provide broad, science-based extension programming on the uses of animal biotechnologies in livestock production systems."

http://animalscience.ucdavis.edu/animalbiotech

Convention on Biological Diversity: "Biotechnology is any technological application that uses biological systems, living organisms or derivatives thereof to make or modify products or processes for specific use."

Genetics/breeding	Nutrition	Health
Artificial insemination	Feed additives: Amino acids, enzymes & probiotics	Molecular diagnostics
Progesterone monitoring	Prebiotics	Recombinant vaccines
Estrus synchronization	Silage additives (enzymes and microbial inoculants)	Conventional vaccines
Invito fetilization and embryo transfer	Ionophores	Sterile insect technique (SIT)
Molecular markers; genomic selection	Single cell proteins	Bioinformatics
Cryopreservation	Solid state fermentation of lignocellulosics	
Semen and embryo sexing	Recombinant somatotropins	**GREEN = Potential for generating impact (time frame <10 years)**
Cloning	Molecular gut microbiology	
Transgenesis		

Ortiz, Rodomiro. 2010. *Agricultural Biotechnologies in Developing Countries: Options and Opportunities in Crops, Forestry, Livestock, Fisheries and Agro-Industry to Face the Challenges of Food Insecurity and Climate Change*.





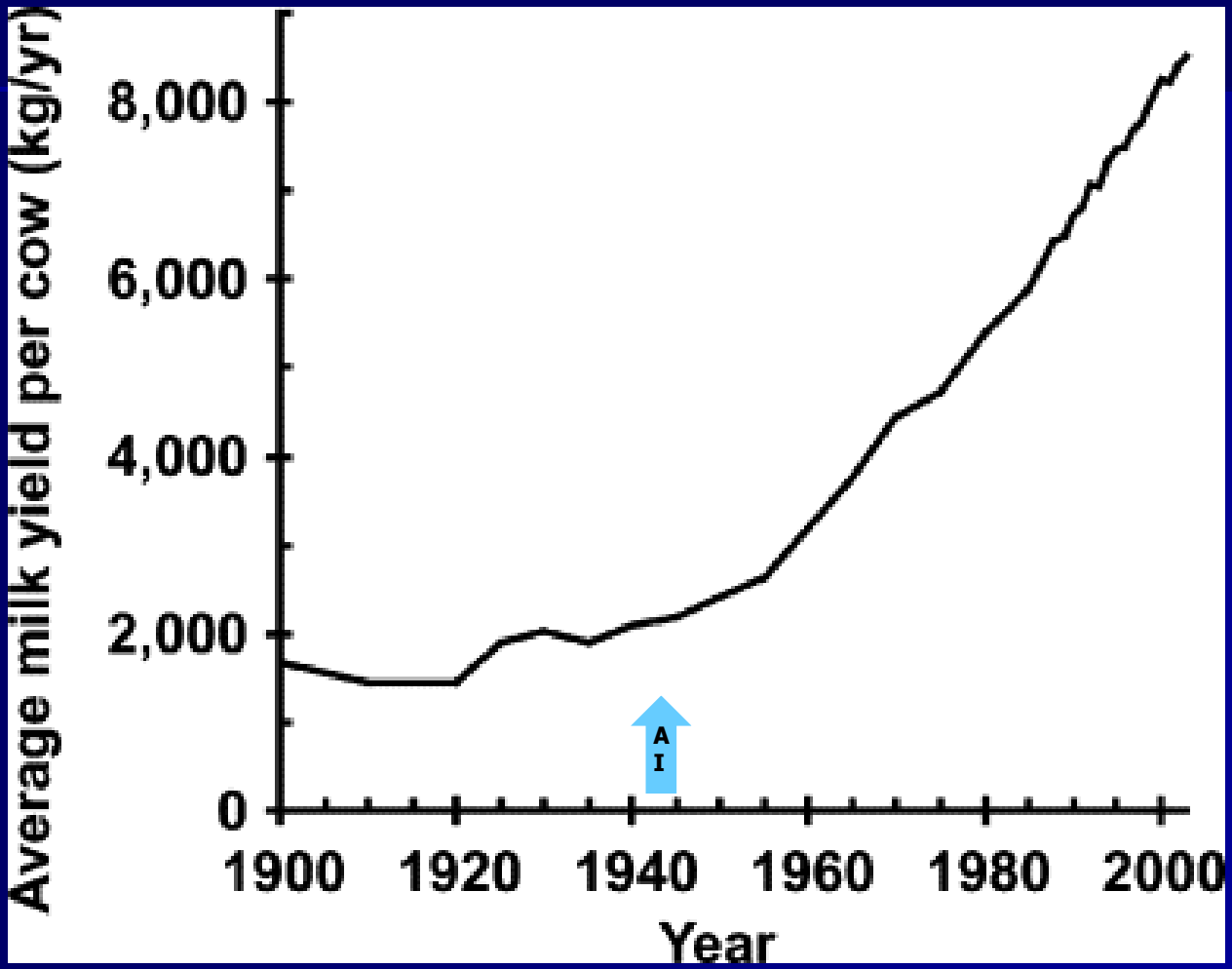


Round Oak Rag Apple Elevation (born 1965) >80,000 daughters, 2.3 million granddaughters, and 6.5 million great-granddaughters

VanRaden, P.M. (2007). **Improving Animals Each Generation by Selecting from the Best Gene Sources.** Available: http://aipl.arsusda.gov/publish/other/2007/Duke07_pvr.pdf.

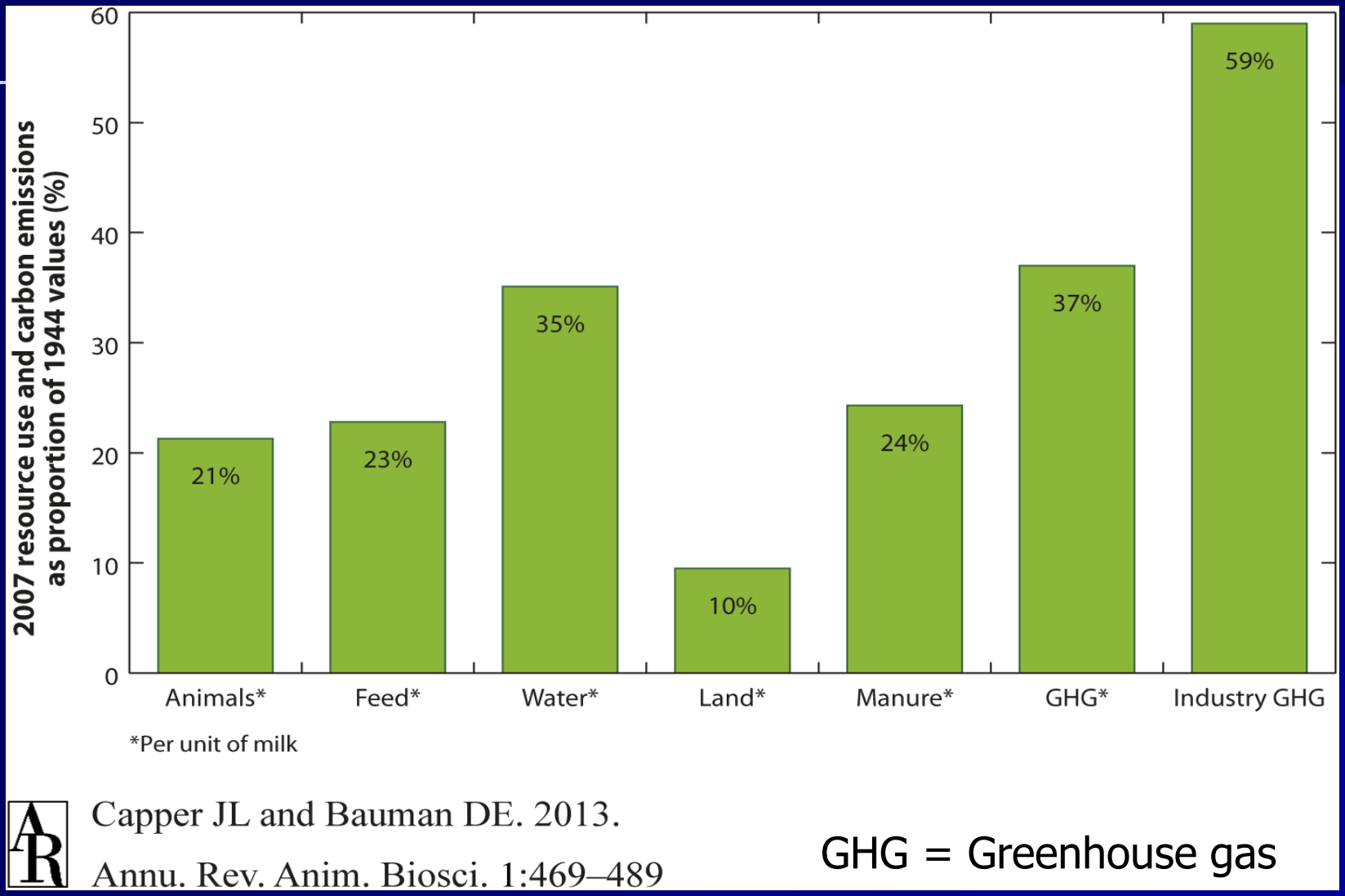
1944: 25.6 million animals; total annual milk production of 53.1 billion kg.
1997: 9.2 million animals; total annual milk production of 84.2 billion kg.

About half of this 369% increase in production efficiency is attributable to genetic improvement enabled by AI



VandeHaar, M.J. and St-Pierre, N. (2006). **Major Advances in Nutrition: Relevance to the Sustainability of the Dairy Industry.** *Journal of Dairy Science* 89, 1280-1291.

Resource use and waste outputs from modern US dairy production systems typical of the year 2007, compared with historical US dairying (characteristic of the year 1944).

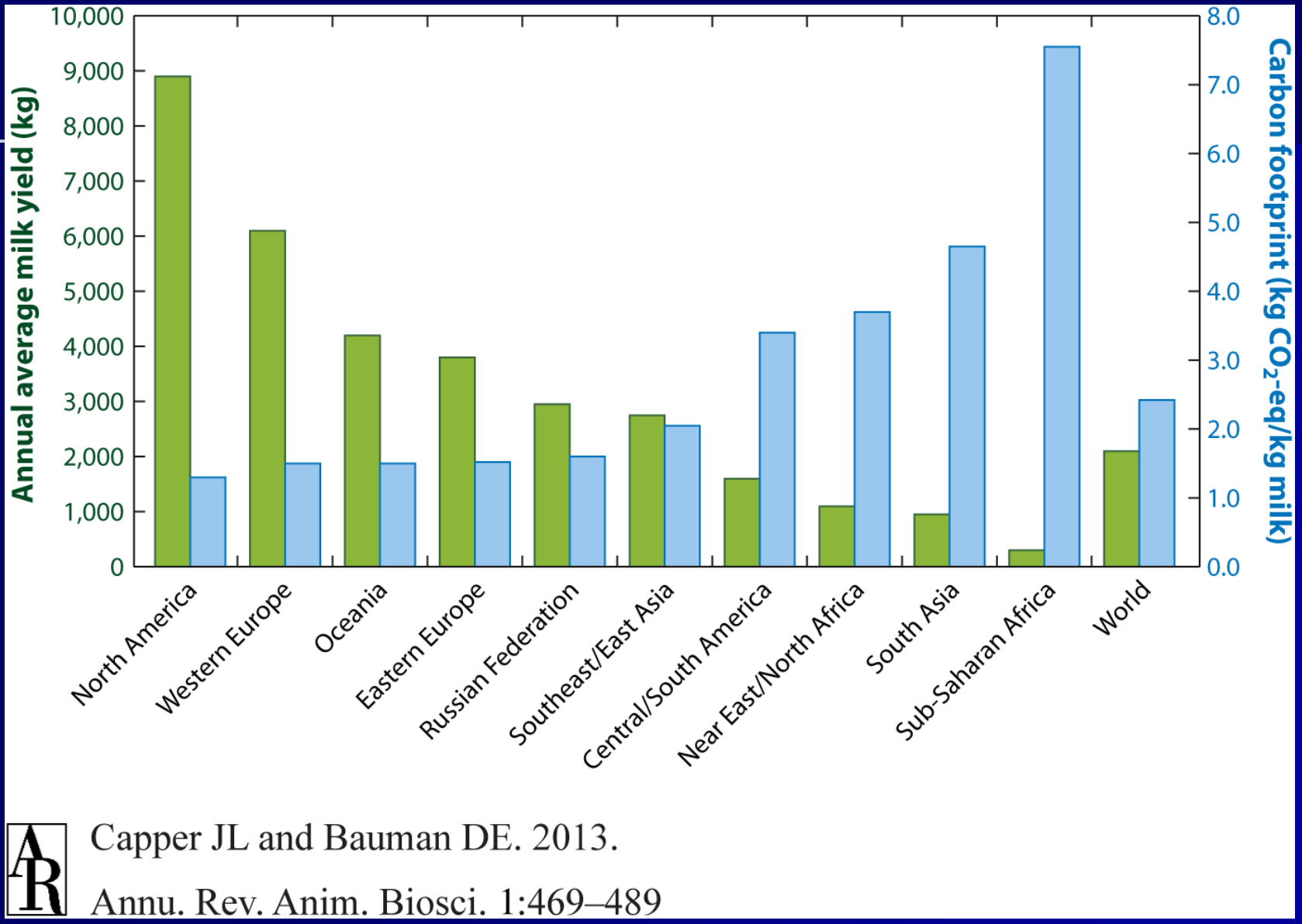


Capper JL and Bauman DE. 2013.

Annu. Rev. Anim. Biosci. 1:469–489

GHG = Greenhouse gas

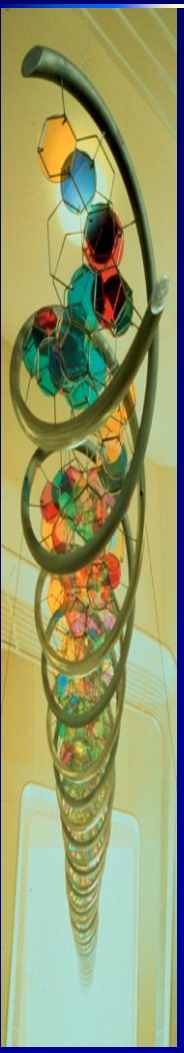
Average annual milk yield and carbon footprint per kg milk - across global regions. Data adapted from FAO.



Capper JL and Bauman DE. 2013.

Annu. Rev. Anim. Biosci. 1:469–489

Current status of animal biotechnologies and factors influencing their applicability in developing countries - GENETICS



	Extent of use	Public and government acceptance	Current technical capability for using technology	Infrastructure and materials and tools available for using technology	Relative cost	Skills required for application	Potential for generating impact (time frame <10 years)
ARTIFICIAL INSEMINATION	++	+++	++	++	++	++	+++
PROGESTERONE MONITORING	+	+++	+	+	++	++	++
ESTRUS SYNCHRONIZATION	+	+++	+	+	++	++	++
IN VITRO FERTILIZATION/ EMBRYO TRANSFER	+	+++	+	+	+++	+++	++
MOLECULAR MARKERS	+	+++	+	+	++	+++	+
CRYOPRESERVATION	+	+++	++	+	++	+++	++
SEMEN AND EMBRYO SEXING	+	+++	+	+	+++	++	++
CLONING	+	+	+	+	+++	+++	+
TRANSGENESIS/GE	0	+	+	+	+++	+++	+






101

GE Chickens That Don't Transmit Bird Flu

Breakthrough could prevent future bird flu epidemics

Suppression of Avian Influenza Transmission in Genetically Modified Chickens

Jon Lyall,[1] Richard M. Irvine,[2] Adrian Sherman,[3] Trevelyan J. McKinley,[1] Alejandro Núñez,[2] Auriol Purdie,[3]* Linzy Outtrim,[2] Ian H. Brown,[2] Genevieve Rolleston-Smith,[3] Helen Sang,[3]† Laurence Tiley[1]†‡

Infection of chickens with avian influenza virus poses a global threat to both poultry production and human health that is not adequately controlled by vaccination or by biosecurity measures. A novel alternative strategy is to develop chickens that are genetically resistant to infection. We generated transgenic chickens expressing a short-hairpin RNA designed to function as a decoy that inhibits and blocks influenza virus polymerase and hence interferes with virus propagation. Susceptibility to primary challenge with highly pathogenic avian influenza virus and onward transmission dynamics were determined. Although the transgenic birds succumbed to the initial experimental challenge, onward transmission to both transgenic and nontransgenic birds was prevented.

The diversity of avian influenza viruses (AIVs) and their propensity for interspecies transmission make them a global threat to animal and public health communities. Cross-species transmission of influenza viruses mediate host species that amplify and diversify virus populations, notably domestic chickens, ducks, and pigs (*1*). Although control of AIV infection in its wild aquatic bird reservoir is impractical, control of AIV in domesticated hosts is

The diversity of viral antigenic sub-

Science 331:223-226. 2011 SCIENCE VOL 331 14 JANUARY 2011 223

www.roslin.ed.ac.uk/public-interest/gm-chickens

Omega-3 Pigs
(Pigs cloned after genetically engineering cell)

BRIEF COMMUNICATIONS

nature biotechnology

Nature Biotechnology 24:435-436. 2006

Generation of cloned transgenic pigs rich in omega-3 fatty acids

Liangxue Lai[1,2,8], Jing X Kang[5,8], Rongfeng Li[1], Jingdong Wang[5], William T Witt[6], Hwan Yul Yong[1], Yanhong Hao[1], David M Wax[1], Clifton N Murphy[1], August Rieke[1], Melissa Samuel[1], Michael L Linville[3], Scott W Korte[4], Rhobert W Evans[7], Thomas E Starzl[6], Randall S Prather[1,2] & Yifan Dai[6]

Meat products are generally low in omega-3 (*n*-3) fatty acids, which are beneficial to human health. We describe the generation of cloned pigs that express a humanized *Caenorhabditis elegans* gene, fat-1, encoding an *n*-3 fatty acid desaturase. The hfat-1 transgenic pigs produce high levels of *n*-3 fatty acids from *n*-6 analogs, and their tissues have a significantly reduced ratio of *n*-6/*n*-3 fatty acids ($P < 0.001$).

The health benefits of long chain *n*-3 fatty acids, found mainly in fish oils, are well recognized. Meat products normally contain small amounts of *n*-3 fatty acids and large amounts of *n*-6 fatty acids[1]

University of Missouri/Massachusetts General Hospital and Harvard Medical School

Mastitis-resistant cows
(inflammation of mammary gland)

nature biotechnology

ARTICLES

Nature Biotechnology 23:445-451. 2005

Genetically enhanced cows resist intramammary *Staphylococcus aureus* infection

Robert J Wall[1], Anne M Powell[1], Max J Paape[2], David E Kerr[3], Douglas D Bannerman[2], Vernon G Pursel[1], Kevin D Wells[4], Neil Talbot[1] & Harold W Hawk[1]

Mastitis, the most consequential disease in dairy cattle, costs the US dairy industry billions of dollars annually. To test the feasibility of protecting animals through genetic engineering, transgenic cows secreting lysostaphin at concentrations ranging from 0.9 to 14 mg/ml in their milk were produced. *In vitro* assays demonstrated the milk's ability to kill *Staphylococcus aureus*. Intramammary infusions of *S. aureus* were administered to three transgenic and ten nontransgenic cows. Increases in milk somatic cells, elevated body temperatures and induced acute phase proteins, each indicative of infection, were observed in all of the nontransgenic cows but in none of the transgenic animals. Protection against *S. aureus* mastitis appears to be achievable with as little as 3 mg/ml of lysostaphin in milk. Our results indicate that genetic engineering can provide a viable tool for enhancing resistance to disease and improve the well-being of livestock.

http://www.nature.com/naturebiotechnology

Fast growing salmon

The founder female was generated in 1989 ~ a quarter century ago

Nature Biotechnology 10:176 – 181. 1992

GROWTH ENHANCEMENT IN TRANSGENIC ATLANTIC SALMON BY THE USE OF AN "ALL FISH" CHIMERIC GROWTH HORMONE GENE CONSTRUCT

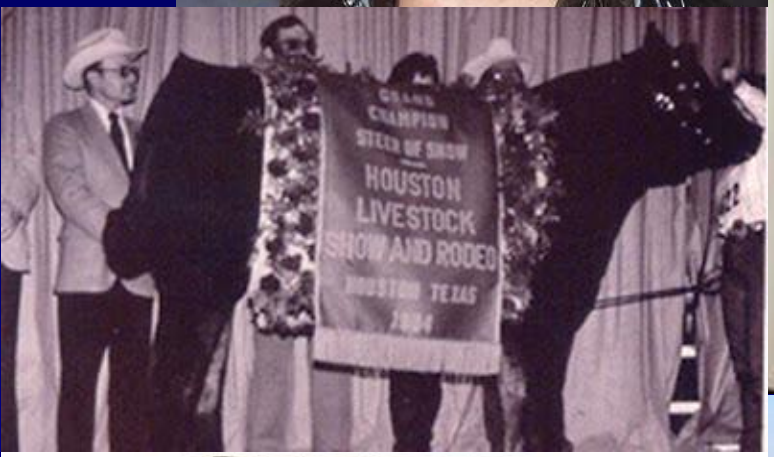
Shao Jun Du, Zhiyuan Gong, Garth L. Fletcher[1], Margaret A. Shears[1], Madonna J. King[1], David R. Idler[1] and Choy L. Hew*

Research Institute, The Hospital for Sick Children and Departments of Clinical Biochemistry and Biochemistry, University of Toronto, Toronto, Canada M5G 1L5. [1]Ocean Sciences Centre, Memorial University of Newfoundland, St. John's, Newfoundland, Canada A1C 5S7. *Corresponding author.

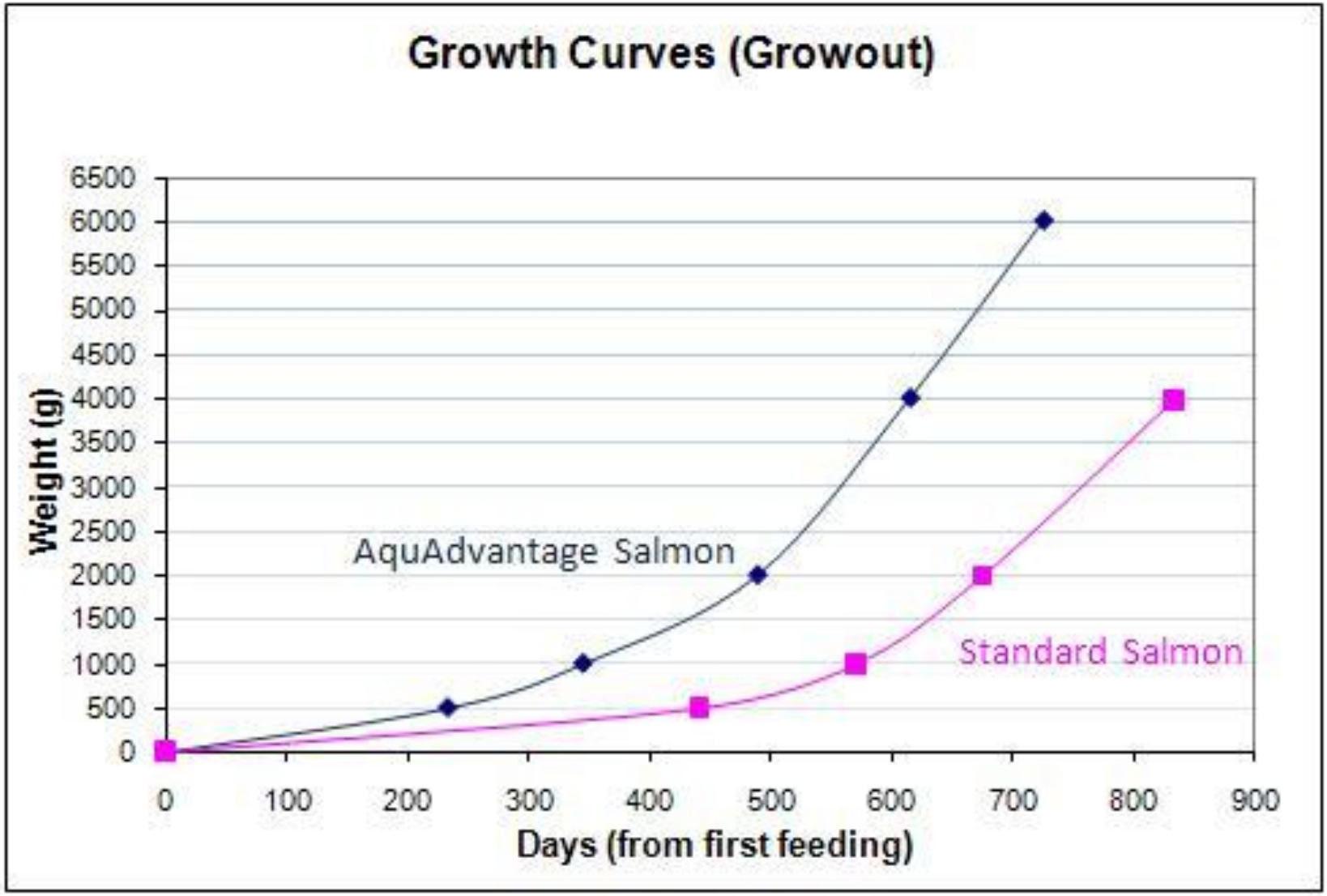
We have developed an "all fish" growth hormone (GH) chimeric gene construct by using an antifreeze protein gene (AFP) promoter from ocean pout linked to a chinook salmon GH cDNA clone. After microinjection into fertilized, nonactivated Atlantic salmon eggs via the micropyle, transgenic Atlantic salmon were generated. The presence of the transgene was

University of Toronto/Memorial University of Newfoundland, Canada


1980's


HOUSTON
LIVESTOCK
SHOW AND RODEO

Fish reach adult size in 16 to 18 months instead of 30 months



Timeline of AquAdvantage regulatory process

24+ years from discovery to application?

Year	Event
1989	• Founder AquAdvantage fish produced in Canada
1995	• FDA review of AquAdvantage salmon begins
2001	• First regulatory study submitted by Aqua Bounty Technologies to U.S. FDA for a New Animal Drug Applications (NADA)
2009	• FDA guidance on how GE animals will be regulated • FDA approval of first GE animal pharmaceutical • Final AquAdvantage regulatory study submitted to FDA
2010	• FDA VMAC meeting on AquAdvantage salmon (9/20/10)
2011	• Political efforts to prevent FDA from regulating GE salmon
2013	• **AquaBounty has expended over $60 million to bring the AquAdvantage salmon through the regulatory approval process *thus far*** (D. Frank, CFO, AquaBounty, pers. comm.) • Still waiting for regulatory decision on AquAdvantage salmon • Delayed approvals diminishing US investment in GE animals • Use of GE animals for food moving to other countries

Sites working on GE livestock for food – 1985
North America, Europe and Australasia

Sites working on GE livestock for food - 2012 Asia and South America are moving forward with this technology in their animal agriculture

My basic question is this

- The first genetically engineered (GE) crops came to the market in 1986
- In 2012 **17.3 million** farmers grew GE crop varieties on > 170 million hectares, and of these > 90% (15 million) were small, resource-poor farmers in developing countries
- Humans and livestock have consumed billions of meals without a single case of harm attributable to the GE nature of the materials consumed
- Currently products developed though the process of GE are singled out and uniquely required to go through regulatory approval
- These regulatory policies add years and millions of dollars to the cost of developing GE crops and animals
- **Is this level of scrutiny aligned to science-based risks associated with this technology, or is this overabundance of precaution making the deployment of this valuable technology beyond the means of all but the largest, multinational corporations, to the detriment of food security globally?**

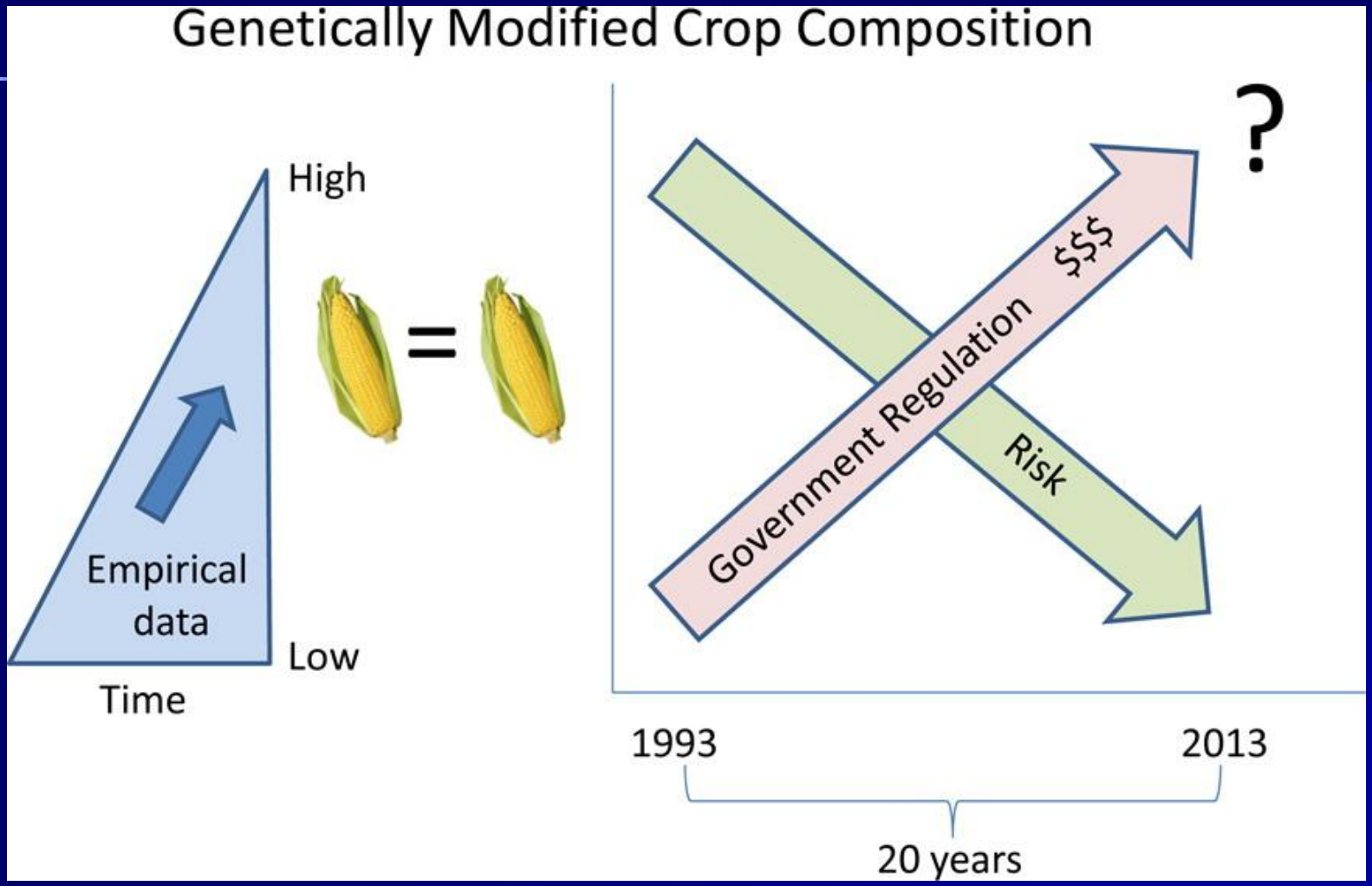
There is no scientific case for a blanket approval of all uses of GE. But equally there is no scientific case for contrived safety testing

There is always the issue of novel proteins or compounds with no history of safe use. These will always have to be tested for toxicity and allergenicity– be they introduced by GE or conventional breeding techniques.

The bulk of safety testing and expense is to detect "unintended" changes specifically resulting from GE

It is continued testing using ever more-expensive techniques including emerging "omics" for these "***unexpected" unintended*** *effects of GE* that is scientifically dubious as the biological relevance of a statistically significant compositional change is unclear – especially in the absence of data for conventional food.

GE process-based "equivalence" studies uniquely required for GE can no longer justified on the basis of scientific uncertainty



Herman RA, Price WD. 2013. **Unintended Compositional Changes in Genetically Modified (GM) Crops: 20 Years of Research**. J Agric Food Chem. 2013 Feb 25.

Unintended effects have not materialized

It seems more scientifically defensible to be able to state that certain likely effects (e.g. novel allergens and toxins, positional insertion effects) have been assessed and found absent, than to admit that one did not know quite what to look for – but found it absent nevertheless

"Skeptics who remain fearful sometimes respond that "absence of evidence is not the same thing as evidence of absence". Yet if you look for something for 15 years and fail to find it, that must surely be accepted as evidence of absence. It is not proof that risks are absent, but proving that something is absent (proving a negative) is always logically impossible*"

* Paarlberg, R. 2010. **GMO foods and crops: Africa's choice**. New Biotechnology 27:609-613

It is time to reconnect the GE regulatory framework to the best available science

How can $60 million be warranted to bring a fast-growing fish to market, when conventional fish (and other animal) breeders routinely develop all manner of fast-growing animals that are associated with the same set of risks?

"Historically, risks to the environment presented by crop plants are low. In these projects, we think what we need to do is to collect scientific data and understand the scientific basis for safe use of GMO products..... *We are not trying to prove how risky it may be by strange imagination or by inventing some special phenomena that do not occur in nature."*

Jia S, Peng Y. 2002. **GMO biosafety research in China.** Environ Biosafety Res. 2002 1(1):5-8.

GE regulatory burdens are not justified by scientific evidence or experience. While regulation to ensure the safety of new technologies is necessary, in a world facing burgeoning demands on agriculture from population growth, economic growth, and climate change, overregulation is an indulgence we can ill afford.

- The trigger for regulatory review should be the novelty of the introduced trait (regardless of how or when it was derived), and *not* the process used to introduce the trait
- The severity of regulatory control should be directly related to the actual, relative risk associated with the novel characteristic (phenotype)
- Phenotypes with a history of safe use should be exempted from regulatory review regardless of the methods used to produce them

Giddings, V., Stepp, M. and M.E. Caine. 2013. Feeding the Planet in a Warming World http://www.itif.org/publications/feeding-planet-warming-world

- **Regulatory frameworks should formally evaluate the reasonable and unique risks associated with the use of GE animals in agricultural systems, and weigh them against those associated with existing conventional systems, and those of inaction (i.e. postponing a regulatory decision). Perhaps more importantly these risks have to be weighed against the benefits.**

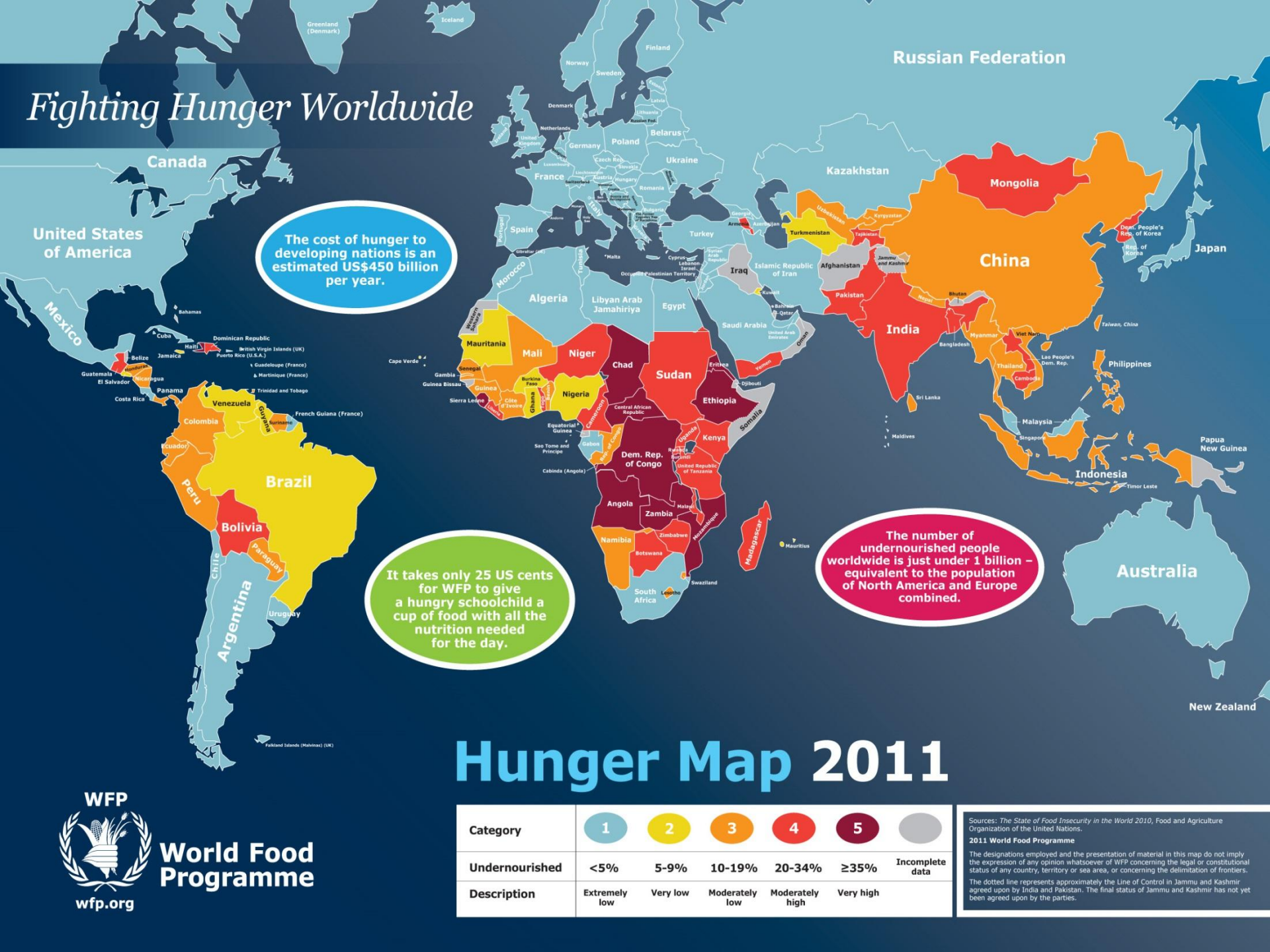
Some animal biotechnology applications, including GE animals, would seem to align with many sustainability goals including improving animal well-being – will they be permitted to do so given current regulatory policy?

- Naturally polled cattle
- Trypanosome resistance
- Sex selection for in dairy and egg industries

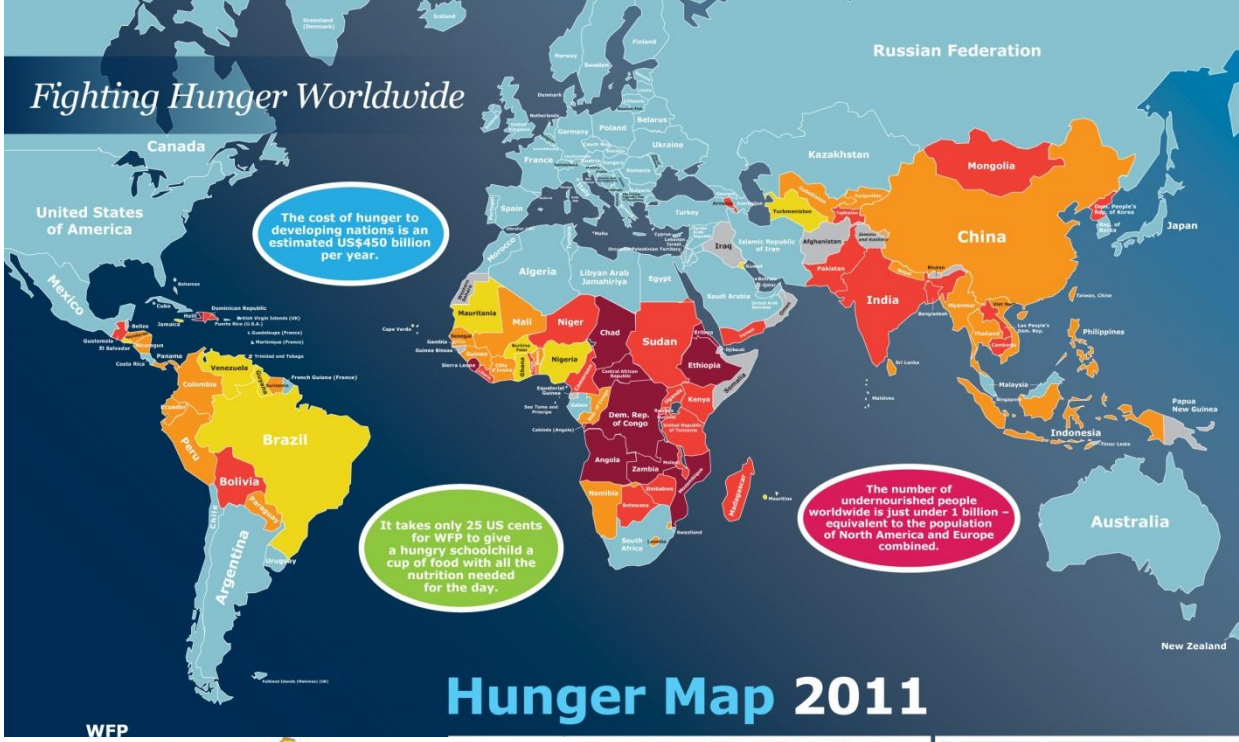
MARK LYNAS – formerly one of the most strident opponents of GE crops and food

"the environmental movement has done more harm with its opposition to genetic engineering than with any other thing we've been wrong about...We've starved people, hindered science, hurt the natural environment, and denied our own practitioners a crucial tool"

Mark Lynas, Lecture to Oxford Farming Conference, 1/3/2013.
http://www.marklynas.org/2013/01/lecture-to-oxford-farming-conference-3-january-2013/


Fighting Hunger Worldwide
The cost of hunger to developing nations is an estimated US$450 billion per year.
It takes only 25 US cents for WFP to give a hungry schoolchild a cup of food with all the nutrition needed for the day.
The number of undernourished people worldwide is just under 1 billion – equivalent to the population of North America and Europe combined.
Hunger Map 2011
WFP
World Food Programme
wfp.org
Category
Undernourished
Description
1
<5%
Extremely low
2
5-9%
Very low
3
10-19%
Moderately low
4
20-34%
Moderately high
5
≥35%
Very high
Incomplete data
Sources: The State of Food Insecurity in the World 2010, Food and Agriculture Organization of the United Nations.
2011 World Food Programme
The designations employed and the presentation of material in this map do not imply the expression of any opinion whatsoever of WFP concerning the legal or constitutional status of any country, territory or sea area, or concerning the delimitation of frontiers.
The dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

“15 years after GMO crops were first planted commercially in the United States, only two governments in Sub-Saharan Africa have given a commercial release to any GMO crops, the Republic of South Africa (for maize, soybean, and cotton), and Burkina Faso (only for cotton).”



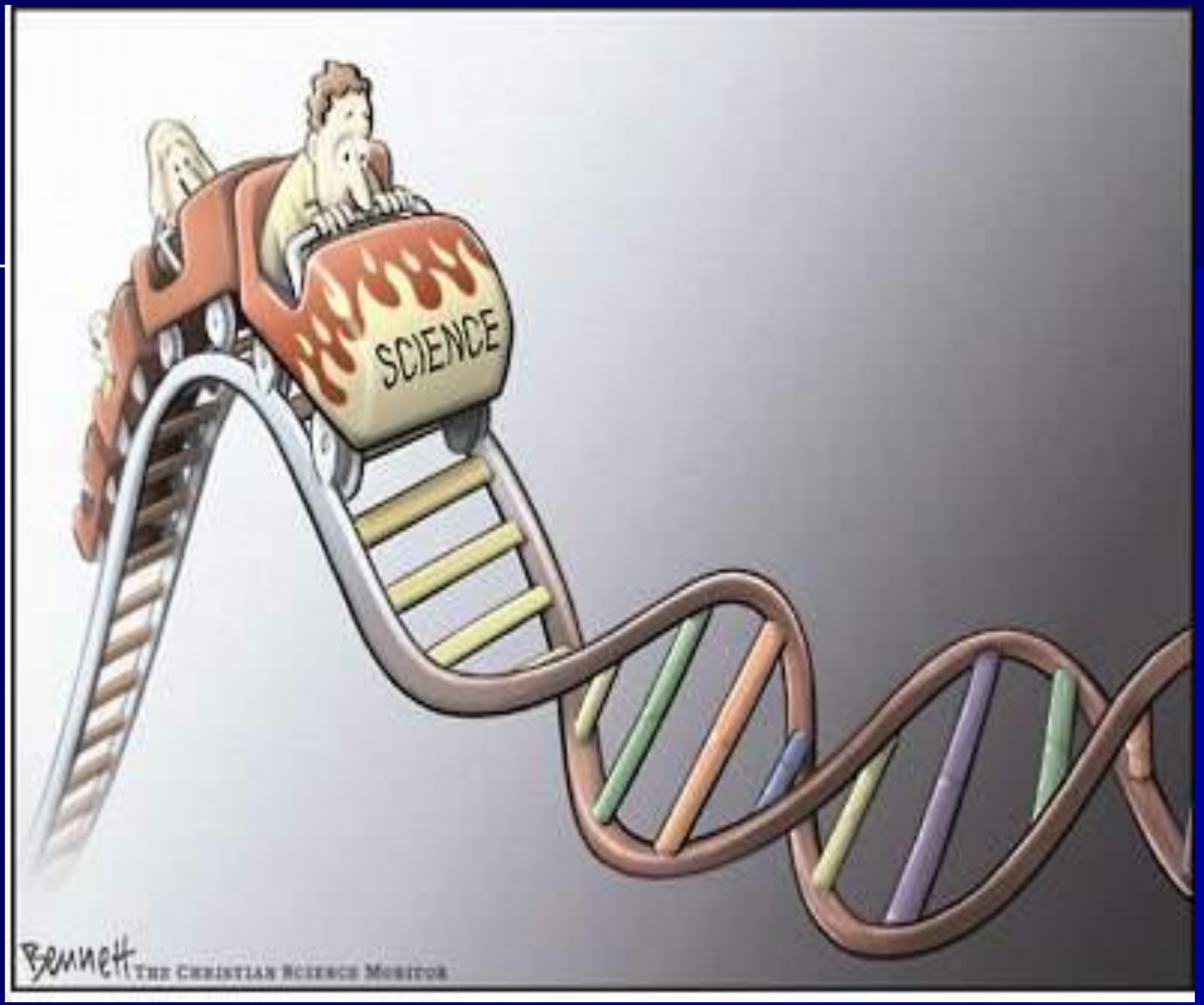
Allows commercial planting of biotech crops

Allows import of biotech crops for food and/or feed

Cruz, Von Mark. V. and R.A. Hautea. 2011. **Global scenario on crop biotechnology: Communication setting.** pp. 1-25. In M.J. Navarro and R.A. Hautea (eds.) Communication challenges and convergence in crop biodiversity. ISAAA and SEARCA, Los Baños, Philippines. Book Chapter.

"I now say that the world has the technology — either available or well advanced in the research pipeline — to feed on a sustainable basis a population of 10 billion people. The more pertinent question today is whether farmers and ranchers will be permitted to use this new technology? While the affluent nations can certainly afford to adopt ultra low-risk positions, and pay more for food produced by the so-called 'organic' methods, the one billion chronically undernourished people of the low income, food-deficit nations cannot."

Norman Borlaug


SCIENCE
Bennett
The Christian Science Monitor