Harvard Journal of Law & Technology
Volume 39, Number 2 Spring 2026

WHEN FOOD BECOMES A DRUG

*Hadar David**

ABSTRACT

This Article examines the regulation of genomic alterations in food animals through genetic engineering — i.e., animals altered for the production of meat, milk, and other animal-derived foods. Despite the potential of genetic engineering to improve sustainability, animal welfare, and food security, only two genetically engineered ("GE") food animals have reached the market in the United States. The central reason lies in a legal framework built on statutes and definitions ill-suited to modern biotechnology. Forty years ago, the United States made a deliberate choice in the 1986 Coordinated Framework for Regulation of Biotechnology to entrench a reliance on existing laws rather than enact new legislation to regulate biotechnology. That approach remains in place today. Regulatory agencies remain compelled to retrofit preexisting statutory frameworks to address novel technologies, resulting in a fragmented and ad hoc regime that continues to fall short of serving the public interest.

In its January 2025 final guidance on "Heritable Intentional Genomic Alterations in Animals," the U.S. Food and Drug Administration reaffirmed its interpretation of genetic alterations in animals as "drugs" under the Federal Food, Drug, and Cosmetic Act ("FDCA"). This interpretation subjects GE food animals to the "new animal drug" premarket approval process designed for pharmaceuticals, despite the fact that the resulting products are foods. This pharma-like model imposes high regulatory burdens that stifle innovation and restrict market entry. The challenges posed by the current approach to regulating GE food animals reveal systemic flaws in the broader biotechnology regulatory system and underscore the urgency of legislative reform.

At the core of this approach lies the FDCA's "food"-"drug" dichotomy. Despite the immense importance of this dichotomy, courts and the FDA have failed to revisit this binary in light of modern science, forcing genetic alterations in GE animals into the "drug" paradigm. Challenging conventional thinking, this Article argues that this

* Doctoral Candidate, Stanford Law School, Knight-Hennessy Scholar. Ph.D. Candidate (Philosophy-Bioethics), Bar-Ilan University. I would like to thank Hank Greely, Eric Hallerman, Amalia Kessler, Rob MacCoun, Thiago Nascimento dos Reis, the participants of the 2024 Law and Society Conference, the Stanford JSD Colloquium, and all the interviewees of this study.

longstanding and rigid dichotomy is obsolete and inadequate for addressing the complexities of modern biotechnology.

Drawing on caselaw, legislative history, statutory interpretation, and interviews with stakeholders in biotechnology and regulatory agencies, the Article offers the most comprehensive examination of the legal, regulatory, and practical consequences of the "drug" paradigm for GE food animals. This Article finds that certain legal alternatives within the existing statutory framework should be considered by the FDA. Nonetheless, it argues that a modern legislative framework — tailored to emerging biotechnologies — is ultimately necessary to balance safety, innovation, and public benefit in this evolving field. As the U.S. government is currently reevaluating biotechnology oversight, this Article arrives at a critical juncture.

TABLE OF CONTENTS

I. INTRODUCTION

Genetic engineering refers to modern biotechnological methods used to modify DNA.[1] An intentional genomic alteration ("IGA") is a heritable DNA change produced by such methods. This change may involve adding, removing, or modifying specific nucleotides or genes.

1. The terminology in biotechnology is not used consistently. Some sources refer to "genetic engineering," or "genetic modification," while others use "gene editing" to describe related technologies. In certain contexts, "genetic engineering" is used to refer to the introduction of genetic material from one species into another, whereas "gene editing" is used to refer to targeted modifications of an organism's existing DNA without the introduction of exogenous genetic material. For purposes of this Article, however, the terms "genetic engineering" and "genetically engineered" are used broadly to encompass any targeted changes in the genome.

Such alterations allow developers to create novel traits in the organism. Over the past few decades, the application of genetic engineering to food has been recognized as a transformative technology.[2] It has the potential to address some of the most pressing challenges facing global food production.[3] The ability to introduce genomic alterations into food animals enables them to become more resistant to disease,[4] grow more efficiently,[5] and contribute to sustainability goals by reducing the environmental footprint of animal agriculture.[6] In an era where climate change, resource scarcity, and growing global food demand put immense pressure on agricultural systems,[7] genetic engineering has the potential to help address these challenges.[8] For example, genetically engineered ("GE") Atlantic salmon that grow faster can increase production efficiency.[9] Likewise, GE cattle with shorter hair are better equipped to withstand rising temperatures.[10]

Despite its potential benefits, the commercialization of GE food animals in the United States remains extremely limited. Only two GE

---

2. *See* Lorena Moeller & Kan Wang, *Engineering with Precision: Tools for the New Generation of Transgenic Crops*, 58 BIOSCI. 391, 391 (2008) ("In the past 25 years, a major revolution in agricultural practice and crop production has occurred. Genetically engineered crops with improved agronomic traits have made the transition from laboratory benches and greenhouses to fields all over the world, where they are being grown commercially.").

3. *See* K.A. McColl, B. Clark & T.J. Doran, *Role of Genetically Engineered Animals in Future Food Production*, 91 AUSTRL. VETERINARY J. 113, 113–14 (2013); *see also* James D. Murray & Elizabeth A. Maga, *Genetically Engineered Livestock for Agriculture: A Generation After the First Transgenic Animal Research Conference*, 25 TRANSGENIC RSCH. 321, 321 (2016) ("The combination of transgenic animal technology and gene editing will become increasingly more important tools to help feed the world."). *See generally* F. Forabosco, M. Löhmus, L. Rydhmer & L.F. Sundström, *Genetically Modified Farm Animals and Fish in Agriculture: A Review*, 153 LIVESTOCK SCI. 1 (2013) (providing a review of research on important economic traits for food production, including swine, chickens, cattle, and fish).

4. *See generally* Kristin M. Whitworth, Raymond R.R. Rowland, Catherine L. Ewen, Benjamin R. Trible, Maureen A. Kerrigan, Ada G. Cino-Ozuna et al., *Gene-Edited Pigs Are Protected from Porcine Reproductive and Respiratory Syndrome Virus*, 34 NATURE BIOTECH. 20 (2016) (reviewing research that uses genetic engineering to confer immunity to a fatal viral disease in pigs).

5. *See* David P. Green, *Genetically Engineered Salmon Approved for Food by US FDA*, 25 J. AQUATIC FOOD PROD. TECH. 145, 145 (2016).

6. *See* Diane Wray-Cahen, Anastasia Bodnar, Caird Rexroad III, Frank Siewerdt & Dan Kovich, *Advancing Genome Editing to Improve the Sustainability and Resiliency of Animal Agriculture*, 3 CABI AGRIC. & BIOSCI. 1, 6 (2022).

7. *See* H. Charles J. Godfray, John R. Beddington, Ian R. Crute, Lawrence Haddad, David Lawrence, James F. Muir et al., *Food Security: The Challenge of Feeding 9 Billion People*, 327 SCIENCE 812, 812 (2010).

8. *See id.* at 815–16.

9. *See* Green, *supra* note 5 ("In this case, the rDNA construct introduces a trait that makes the AquAdvantage Salmon grow faster.").

10. *See* U.S. FOOD & DRUG ADMIN., RISK ASSESSMENT SUMMARY: VMF 006-378 2 (2025) (noting that "[t]he IGA . . . result[ed] in a short, 'slick' haircoat that has been linked to increased heat tolerance").

food animals have reached the market,[11] a stark contrast to the comparatively rapid and widespread adoption of GE plant varieties.[12] This Article argues that a central reason for this slow development and commercialization of GE food animals lies in a flawed legal framework built on statutes and definitions ill-suited to modern biotechnology.[13]

Forty years ago, the United States made a deliberate choice in the 1986 Coordinated Framework for Regulation of Biotechnology ("1986 Coordinated Framework") to entrench a reliance on existing laws rather than enact new legislation to regulate biotechnology.[14] That approach remains in place today.[15] Regulatory agencies remain compelled to retrofit preexisting statutory frameworks to address novel technologies, resulting in a fragmented and ad hoc regime[16] that continues to fall short of serving the public interest.

---

11. *See* Alison L. Van Eenennaam, *New Genomic Techniques (NGT) in Animals and Their Agri/Food/Feed Products*, 20 EFSA SUPPORTING PUBL. 1, 7 (2023). The first GE food animal to reach the market was the AquAdvantage salmon. Heidi Ledford, *Salmon Is First Transgenic Animal to Win U.S. Approval for Food*, NATURE MAG. (Nov. 19, 2015), https://www.nature.com/articles/nature.2015.18838 [https://perma.cc/5RLS-UCGP]. However, it was recently withdrawn from the market due to the company's financial difficulties. *See AquaBounty Announces Plans to Cease Fish Farming Operations*, AQUABOUNTY TECH. (Apr. 3, 2024), https://investors.aquabounty.com/news-releases/news-release-details/aquabounty-announces-plans-cease-fish-farming-operations [https://perma.cc/QUN2-PT37]. The second product to reach the market was the GalSafe pig. It is marketed directly to consumers, not through conventional market channels. *See GalSafe Pork*, AMAROO HILLS, https://amaroohills.com/collections/gasafe-pork [https://perma.cc/GW62-QQ42]. Note that, more recently, the FDA approved another GE product only after a lengthy and costly regulatory process. However, the product — pigs engineered to be immune to porcine reproductive and respiratory syndrome ("PRRS") — has not yet reached the commercial market. *See FDA Says GM Pigs Safe to Eat*, 43 NATURE BIOTECH. 839, 839 (2025); *Annual Report 2024*, GENUS (Sep. 4, 2024), https://www.genusplc.com/media/esef/genus-annual-report-2024.html [https://perma.cc/4T8M-9PNL] (reporting gene-editing expenses of £13.7 million in FY2024 and FY2023), at 27.

12. *See generally* Jorge Fernandez-Cornejo, Seth Wechsler, Mike Livingston & Lorraine Mitchell, *Genetically Engineered Crops in the United States*, 162 U.S. DEP'T AGRIC. ECON. RSRCH. REP. (2014) (showing that the adoption of genetically engineered crops by U.S. farmers is widespread and that U.S. consumers regularly consume many products derived from such crops); NAT'L ACADS. OF SCIS., ENG'G & MED., GENETICALLY ENGINEERED CROPS: EXPERIENCES AND PROSPECTS 73–74 (2016) (detailing the global distribution of GE crops, showing that as of 2015, 12% of global cropland produces GE crops).

13. *See* J.D. Murray & E.A. Maga, *A New Paradigm for Regulating Genetically Engineered Animals That Are Used as Food*, 113 PROC. NAT'L ACAD. SCIS. 3410, 3411–12 (2016) (describing failures of current paradigm for regulation of GE animals in the United States and advocating for "review[ing] the approach . . . to bring it in line with a traditional, scientifically founded, product-based, risk-benefit analysis").

14. *See* Coordinated Framework for Regulation of Biotechnology, 51 Fed. Reg. 23302 (Jun. 26, 1986) [hereinafter 1986 Coordinated Framework] ("Upon examination of the existing laws available for the regulation of products developed by traditional genetic manipulation techniques, the working group concluded that, for the most part, these laws as currently implemented would address regulatory needs adequately.").

15. *See* Off. Sci. & Tech. Pol'y, Update to the Coordinated Framework for the Regulation of Biotechnology (2017) [hereinafter 2017 Coordinated Framework].

16. *See id.* at 30–35 (providing a table summarizing responsibilities among agencies for biotechnology products).

Under this framework, the regulation of genetic engineering in animals falls mostly under the jurisdiction of the U.S. Food and Drug Administration ("FDA").[17] The FDA asserted its authority over IGAs in animals, including food animals, through a legal interpretation of the federal FDCA ("FDCA"), classifying these alterations as "drugs" under the statute.[18] In January 2025, the FDA finalized its guidance formalizing this interpretation and outlining the regulatory expectations for IGAs in animals.[19] Although food products from GE animals are intended for consumption as food, they are regulated not as food but as drugs, triggering a premarket approval process that involves rigorous and time-intensive data requirements.[20] The challenges posed by the current approach to regulating GE food animals reveal systemic flaws in the broader biotechnology regulatory system and underscore the urgency of legislative reform. At the core of the current regulatory approach lies the FDCA's rigid "food"-"drug" dichotomy.[21] Courts and the FDA have failed to revisit this binary distinction in light of modern science, forcing genetic alterations in GE food animals into the "drug" paradigm.[22] This longstanding and rigid dichotomy is obsolete and inadequate for addressing the complexities of modern biotechnology.

This Article demonstrates that the application of the "drug" paradigm to regulatory oversight of GE food animals — through the classification of IGAs as new animal drugs — has had a profound impact on both industry and academic stakeholders. While existing literature addresses the regulatory delays and costs, this Article moves beyond those observations.[23] It offers a detailed examination of how the regulatory structure directly affects developers of GE food animals and the resulting broader industry dynamics. Drawing on interviews with key stakeholders across biotechnology, agriculture, and regulatory

---

17. *See* U.S. FOOD & DRUG ADMIN., GUIDANCE FOR INDUSTRY #187A: HERITABLE INTENTIONAL GENOMIC ALTERATIONS IN ANIMALS: RISK-BASED APPROACH (2024) (hereinafter GUIDANCE 187A).

18. *See* 21 U.S.C. § 321(g)(1); U.S. FOOD & DRUG ADMIN., GUIDANCE FOR INDUSTRY #187B: HERITABLE INTENTIONAL GENOMIC ALTERATIONS IN ANIMALS: THE APPROVAL PROCESS 1–2 (2025) [hereinafter GUIDANCE 187B]; 2017 Coordinated Framework, *supra* note 15, at 18–19.

19. *See* GUIDANCE 187B, *supra* note 18.

20. *See id.* at 19–20 (detailing the premarket approval process for GE animals).

21. *See* 21 U.S.C. § 321(g)(1) (defining "drug"); 21 U.S.C. § 321(f) (defining "food"); *see also* Lewis A. Grossman, *Food, Drugs, and Droods: A Historical Consideration of Definitions and Categories in American Food and Drug Law*, 93 CORN. L. REV. 1091, 1115 (2007) ("[C]ongress exempted 'food' from the new category of structure-function drugs; it did not want to convert every diet food into a drug. Moreover . . . the 'food' exclusion probably reflected the fact that 'all food is intended to, and in fact does, affect the structure and function of the body.'").

22. *See* Ins. for Fisheries v. Hahn, 424 F. Supp. 3d 740, 755 (N.D. Cal. 2019) ("An rDNA construct that is 'intended to affect the structure or any function of the body of man or other animals' is a drug under the FDCA.") (citing 21 U.S.C. § 321(g)(1)(C)).

23. *See infra* Part III.

agencies — including the FDA and the U.S. Department of Agriculture ("USDA")[24] — this study provides insights into the developmental process of GE food animals, the regulatory challenges faced by stakeholders, and the perspectives of government officials on these issues.[25]

Two principal effects emerge. First, the complexity, cost, and duration of the FDA's drug approval process have significantly narrowed the field of actors willing or able to engage in GE food animal development.[26] Second, the scope of innovation has been curtailed, as regulatory burdens have led to a concentration on a limited number of commercially viable traits, while more experimental or socially beneficial applications remain unexplored.[27] The regulatory hurdles that developers face in gaining premarket approval for GE food animals do not impact solely those developers. Society stands to lose out on products that may never be invented due to these obstacles.[28]

Having shown that the FDA's "drug" classification for genomic alterations in animals suppresses innovation, this Article turns to its second contribution: examining the legal basis of that interpretation and exploring potential alternatives, including legislative reform, to address these concerns. Under the FDCA, a drug is defined as "articles (other than food) intended to affect the structure or any function of the body of man or other animals."[29] The FDA construes the "article" in this context to be the genetic alteration within the animal.[30] This Article evaluates four possible readings of what that "article" might be: (1) the DNA construct introduced into the embryo; (2) the embryonic cells containing the induced alteration; (3) the altered genomic sequence within the animal (the FDA's interpretation); and (4) the animal itself. Drawing on interviews, legal analysis, legislative history, and caselaw, this Article argues that none of these interpretations convincingly fits the statutory definition.

---

24. The views shared in interviews are personal views of the interviewees that cannot be attributed to the agencies.

25. *See infra* Part III.

26. *See infra* Section III.B.1.

27. *See infra* Section III.B.2.

28. *See* Alison L. Van Eenennaam, *GMOs in Animal Agriculture: Time to Consider Both Costs and Benefits in Regulatory Evaluations*, 4 J. ANIMAL SCI. & BIOTECH. 1, 10 (2013); Alison L. Van Eenennaam, Felipe De Figueiredo Silva, Josephine F. Trott & David Zilberman, *Genetic Engineering of Livestock: The Opportunity Cost of Regulatory Delay*, 9 ANN. R. ANIMAL BIOSCIS. 453, 453 (2021) (showing how "[d]elays of 5 or 10 years in the commercialization of GE livestock beyond the normative 10-year GE product evaluation period were associated with billions of dollars in opportunity costs and reduced global food security").

29. 21 U.S.C. § 321(g)(1)(C).

30. *See* GUIDANCE 187A, *supra* note 17, at 3 ("The article we are regulating is the specific DNA alteration at each site in the genome where the intended alteration (i.e., insertion, substitution, or deletion) occurs.").

In the post-*Chevron* era, following *Loper Bright Enterprises v. Raimondo*, [31] the landscape of judicial review over statutory interpretations has shifted. The power of agencies to defend their statutory interpretations has been diminished, with courts now directed under *Loper Bright* to exercise "their independent judgment in deciding whether an agency has acted within its statutory authority."[32] Given this development, courts may be more inclined to scrutinize and potentially challenge the FDA's classification of genetic modifications in GE food animals as "drugs" if challenged in court. Courts could adopt alternative interpretations of the statute, diverging from the FDA's longstanding position. Therefore, faced with this possibility, it is time to reevaluate and possibly redirect the regulatory framework governing GE food animals.

This Article explores several legal alternatives for regulating GE food animals, including classifying them as "food"[33] or expanding the "enforcement discretion" that the FDA may exercise, whereby the agency may choose not to require premarket approval for certain products under specific criteria.[34] Yet none of these options offers a fully satisfactory solution. Ultimately, the analysis suggests that the most effective and principled approach for the long term would be the enactment of a new legislative framework specifically designed for emerging biotechnologies. Such a framework would provide regulatory clarity, balance risk with innovation, and reflect the unique considerations posed by new genetic technologies, and specifically by GE food animals. Modern legislative models from other countries, particularly Argentina and Brazil,[35] may offer useful starting points for considering an appropriate regulatory scheme.

With the U.S. government currently reevaluating biotechnology oversight, this Article arrives at a critical juncture.[36] Recognizing the urgency of the moment, Congress established the National Security Commission on Emerging Biotechnology on a bipartisan basis.[37] The Commission was granted a mandate to conduct a comprehensive review of the technology's impact on national security and to provide recommendations that preserve American dominance in the field.[38]

The remainder of this Article proceeds in four parts. Part II offers a technological overview of genetic engineering in animals and outlines

---

31. 603 U.S. 369 (2024).
32. *Id.* at 412.
33. *See* 21 U.S.C. § 321(F).
34. *See* GUIDANCE 187A, *supra* note 17, at 5.
35. *See infra* Section V.D.
36. *See* NAT'L SEC. COMM'N ON EMERGING BIOTECH., MODERNIZING MEDICAL BIOTECHNOLOGY REGULATION (2026).
37. *Id.*; NAT'L SEC. COMM'N ON EMERGING BIOTECH., CHARTING THE FUTURE OF BIOTECHNOLOGY: AN ACTION PLAN FOR AMERICAN SECURITY AND PROSPERITY (2025).
38. *See id*. at 34.

the statutory and regulatory framework governing GE food animals in the United States. Part III turns to the practical implications of that framework, analyzing its effects on industry and academic researchers. Part IV shifts to a normative inquiry, examining the legal foundations of the FDA's decision to regulate genomic alterations in animals under the "drug" paradigm. Finally, Part V considers legal alternatives to the current approach, assessing their feasibility and potential to better balance public safety with innovation in agricultural biotechnology.

II. THE TECHNOLOGY AND REGULATION OF GENOMIC ALTERATIONS IN ANIMALS

Altering the DNA of food animals is a longstanding practice in agriculture.[39] Farmers have employed selective breeding for centuries, pairing animals with desirable traits to enhance food production or modify characteristics like aggressiveness in chickens.[40] But selective breeding is time-consuming and imprecise, lacking control over particular DNA alterations and phenotypic outcomes.[41] IGAs offer precise genetic enhancements in food animals in a short time to achieve desired traits by modifying an animal's DNA using modern molecular technologies.[42] This encompasses various changes in DNA sequences, including insertions, substitutions, or deletions, either targeted or random, within the animal's genome.[43]

One prominent method is recombinant DNA ("rDNA") technology, which entails extracting DNA from one source (e.g., mice) and integrating it into the DNA sequence of another organism (e.g., fish).[44] This approach has been utilized for over five decades, witnessing continuous advancements in genome manipulation methods. The earliest instances of altering animal DNA using this method date back to the 1980s, starting with mice[45] and subsequently

39. *See* JAY L. LUSH, ANIMAL BREEDING PLANS 24 (1943).

40. *See* A.M. Guhl, J.V. Craig & C.D. Mueller, *Selective Breeding for Aggressiveness in Chickens*, 39 POULTRY SCI. 970, 970 (1960) (demonstrating that selective breeding can be used to produce significant differences in aggressiveness).

41. *See* Eric M. Hallerman, Justin P. Bredlau, Luiz Sergio A. Camargo, Maria Lucia Zaidan Dagli, Margaret Karembu, Godfrey Ngure et al., *Towards Progressive Regulatory Approaches for Agricultural Applications of Animal Biotechnology*, 31 TRANSGENIC RSCH. 167, 167–70 (2022).

42. *See* GUIDANCE 187B, *supra* note 18, at 1.

43. *See id.* at 1–2.

44. *See* Suliman Khan, Muhammad Wajid Ullah, Rabeea Siddique, Ghulam Nabi, Sehrish Manan, Muhammad Yousaf et al., *Role of Recombinant DNA Technology to Improve Life*, 2016 INT'L J. GENOMICS 1, 2–3, 5 (2016).

45. *See generally* Ralph L. Brinster, Howard Y. Chen, Myrna Trumbauer, Allen W. Senear, Raphael Warren & Richard D. Palmiter, *Somatic Expression of Herpes Thymidine Kinase in Mice Following Injection of a Fusion Gene into Eggs*, 27 CELL 223 (1981) (describing the first implementation of the technology in mice).

extending to rabbits, sheep, and pigs.[46] Throughout the years, new methodologies have emerged, with one of the most significant advancements being CRISPR (clustered regularly interspaced short palindromic repeats) technology. CRISPR enables developers to target and precisely modify virtually any segment of an organism's DNA.[47] Compared to traditional techniques, CRISPR offers more precision, affordability, and ease of use.[48] CRISPR also allows targeted modifications within the animal genome without importing genes from another organism.[49] Other methods build on CRISPR to enhance the precision of the intended genomic change.[50]

GE animals serve many functions, including pharmaceutical production,[51] organ transplantation,[52] and food industry advancements.[53] In agriculture, the technology can improve livestock production, such as creating cows that produce healthier milk.[54] Therefore, GE animals play an increasingly vital role in human sustenance.[55] Genetic engineering presents a unique opportunity to enhance food production while minimizing resource consumption and reducing the environmental footprint.[56] Additionally, genetic engineering can be utilized to create safer and more allergen-free food products.[57]

---

46. *See generally* Robert E. Hammer, Vernon G. Pursel, Caird E. Rexroad, Jr., Robert J. Wall, Douglas J. Bolt, Karl M. Ebert et al., *Production of Transgenic Rabbits, Sheep, and Pigs by Microinjection*, 315 NATURE 680 (1985) (reporting the integration of foreign genes in rabbits, sheep, and pigs).

47. *See* F. Ann Ran, Patrick D. Hsu, Chie-Yu Lin, Jonathan S. Gootenberg, Silvana Konermann & Alexandro E. Trevino et al., *Double Nicking by RNA-Guided CRISPR Cas9 for Enhanced Genome Editing Specificity*, 154 CELL 1380, 1380–81 (2013).

48. *See* Hallerman et al., *supra* note 41, at 169–70, 177.

49. *See id.* at 169–70.

50. *See* Ariel Kantor, Michelle E. McClements & Robert E. MacLaren, *CRISPR-Cas9 DNA Base-Editing and Prime-Editing*, 21 INT'L J. MOLECULAR SCIS. 6240, 6240–41 (2020) (describing base-editing and prime-editing).

51. *See* Louis-Marie Houdebine, *Production of Pharmaceutical Proteins by Transgenic Animals*, 32 COMPAR. IMMUNOLOGY, MICROBIOLOGY & INFECTIOUS DISEASES 107, 118 (2009).

52. *See* David K.C. Cooper, *A Brief History of Cross-Species Organ Transplantation*, 25 BAYLOR UNIV. MED. CTR. PROC. 49, 53–54 (2012); Stephen P. Squinto, *Genetically Modified Animal Organs for Human Transplantation*, 21 WORLD J. SURGERY 939, 939 (1997).

53. *See* McColl et al., *supra* note 3.

54. *See* R.J. Wall, D.E. Kerr & K.R. Bondioli, *Transgenic Dairy Cattle: Genetic Engineering on a Large Scale*, 80 J. DAIRY SCI. 2213, 2220 (1997).

55. *See* Hannah Ritchie, Pablo Rosado & Max Roser, *Meat and Dairy Production*, OUR WORLD IN DATA (Dec. 2023), https://ourworldindata.org/meat-production [https://perma.cc/M9KH-ZXME] (showing figures with the growth of meat production indicating that global meat production has increased rapidly over the past fifty years).

56. Christine Tait-Burkard, Andrea Doeschi-Wilson, Mike J. McGrew, Alan L. Archibald, Helen M. Sang, Ross D. Houston et al., *Livestock 2.0 — Genome Editing for Fitter, Healthier, and More Productive Farmed Animals*, 19 GENOME BIOLOGY 204, 206 (2018).

57. *See, e.g.*, *FDA Approves First-of-Its-Kind Intentional Genomic Alteration in Line of Domestic Pigs for Both Human Food, Potential Therapeutic Uses*, U.S. FOOD & DRUG

An illustrative example of GE's potential to impact human food consumption is the GalSafe pig. In December 2020, the FDA approved a first-of-its-kind IGA in a line of pigs that aims to eliminate alpha-gal sugar on the surface of pig cells.[58] This alteration allows safe pork consumption for individuals with Alpha-Gal Syndrome who have allergic reactions to alpha-gal sugar.[59] Another notable example is the AquAdvantage salmon, which has been genetically engineered to grow faster than its non-engineered counterpart.[60]

Despite its considerable potential and diverse applications, genetic engineering has also elicited suspicions and doubts. Concerns arise regarding the risks associated with GE animals for food production. Two primary risks accompany the consumption of GE food animals: health risks and environmental risks.[61]

While precise, genetic engineering can result in errors in altering an animal's genome, leading to unintended changes in the animal's genetic makeup.[62] Such alterations may arise due to various factors, including, for example, off-target effects, that is, unintended genetic modifications that occur at locations in the genome other than the intended target site.[63] These unintended changes could potentially result in genome instability, the emergence of new unintended genes, or the inadvertent activation or deactivation of existing genes.[64] While the likelihood of such events is diminishing as technology advances,[65] the possibility remains.

ADMIN. (Dec. 14, 2020), https://www.fda.gov/news-events/press-announcements/fda-approves-first-its-kind-intentional-genomic-alteration-line-domestic-pigs-both-human-food [https://perma.cc/96XF-6VV2].

58. *Id.*

59. *Id.*; GalSafe Pork, AMAROO HILLS, https://amaroohills.com/collections/gasafe-pork [https://perma.cc/GW62-QQ42] (providing an example of how GalSafe pork is marketed as pork that "do[es] not contain detectable levels of alpha-gal").

60. Margaret R. Grossman, *Genetically Engineered Animals in the United States: The AquAdvantage Salmon*, 11 EUR. FOOD & FEED L. REV. 190, 193 (2016).

61. *See generally* NAT'L ACADS. OF SCIS., ENG'G, & MED., *Potential Hazards to Animals and Consumers*, in HERITABLE GENETIC MODIFICATION IN FOOD ANIMALS 52 (2025) (addressing issues regarding animal safety, food safety, and food composition associated with GE food development); Artemis Dona & Ioannis S. Arvanitoyannis, *Health Risks of Genetically Modified Foods*, 49 CRITICAL REVS. FOOD SCI. & NUTRITION 164 (2009) (providing an overview and analysis of potential health risks associated with GE foods); NAT'L RSCH. COUNCIL, *Environmental Concerns, in* ANIMAL BIOTECHNOLOGY: SCIENCE-BASED CONCERNS 73 (2002) (assessing environmental concerns linked to GE foods).

62. Saqib H. Hadri, Abdullah Tariq, Sawera Asif, Sania Abid, Mah Jabeen, Amina Azam et al., *CRISPR-Cas9 Knockout of the β-Lactoglobulin Gene in Dairy Animals: A Review*, 4 FOOD & HUMAN. 1, 5 (2025) ("The main challenge associated with CRISPR/Cas9 applications lies in producing unexpected or unapproved mutations in the genome.").

63. *Id.* at 5–6.

64. Laura R. Epstein, Stella S. Lee, Mayumi F. Miller & Heather A. Lombardi, *CRISPR, Animals, and FDA Oversight: Building a Path to Success*, 118 PROC. NAT'L ACAD. SCIS. 1, 1–2 (2021).

65. *Id.*

Not all unintended changes pose inherent dangers; most are probably harmless.[66] However, vigilance regarding unintended genetic changes remains essential in ensuring the safety of products derived from GE animals. Some effects remain unpredictable due to our limited understanding of gene regulation and interactions between genes.[67] With regard to health, such unpredictability poses risks in the possible creation of substances in the animal body that could be toxic or allergenic to humans.[68] These risks extend to the welfare of both human consumers and animals.[69] However, it is important to note that the occurrence of unintended effects is not exclusive to genetic engineering. Such occurrences are also possible in conventional breeding practices.[70]

Environmental risks associated with GE animals in food production can manifest in various forms. Determining these risks, especially those concerning indirect causal pathways, is challenging.[71] These risks primarily stem from ecological interactions and the consequences of GE animals interacting with their environment.[72] Consider the case of fast-growing salmon. If released into the wild, their rapid growth could potentially disrupt the ecosystem by outcompeting native species for resources.[73] These complex interactions underscore the importance of thoroughly assessing and mitigating environmental risks associated with GE animals in food production.[74]

The risks associated with genetic engineering in livestock ultimately prompted the FDA to regulate this technology. As discussed

---

66. Alison L. Van Eenennaam & Maci L. Mueller, *Current State of Genome Editing and What It Means to Beef Producers*, PROCS., APPLIED REPROD. STRATEGIES BEEF CATTLE 1, 11 (2022).

67. Harry A. Kuiper, Gijs A. Kleter, Hub P. J. M. Noteborn & Esther J. Kok, *Assessment of the Food Safety Issues Related to Genetically Modified Foods*, 27 PLANT J. 503, 515 (2001).

68. Wiktoria Urban, Marta Kropacz, Marksymilian Lach & Anna Jankowska, *CRISPR-Cas9 in the Tailoring of Genetically Engineered Animals*, 47 CURRENT ISSUES MOLECULAR BIOLOGY 1, 9–10 (2025); NAT'L ACADS. OF SCIS., ENG'G, & MED., *supra* note 61, at 59–62.

69. NAT'L ACADS. OF SCIS., ENG'G, & MED., *supra* note 61, at 55–56.

70. Kuiper et al., *supra* note 67, at 515; *see also* Dale E. Shuster, Marcus E. Kehrli, Jr., Mark R. Ackermann & Robert O. Gilbert, *Identification and Prevalence of a Genetic Defect That Causes Leukocyte Adhesion Deficiency in Holstein Cattle*, 89 PROC. NAT'L ACAD. SCIS. 9225, 9228 (1992) (showing how selective breeding in the 1950s led to the spread of genetic diseases within the dairy cattle population).

71. Hallerman et al., *supra* note 41, at 177 ("[I]t is unlikely that all possible harms would be known a priori, particularly for any indirect causal pathways, and quantitative estimation of P(H|E) is difficult.").

72. *See* Allison A. Snow, David Andow, Paul Gepts, Eric M. Hallerman, Alison G. Power, James M. Tiedje et al., G*enetically Engineered Organisms and the Environment: Current Status and Recommendations*, 15 ECOLOGICAL APPLICATIONS 377, 390 (2005).

73. Eric M. Hallerman, *Application of Risk Analysis to Genetic Issues in Aquaculture*, in FAO FISHERIES AND AQUACULTURE TECHNICAL PAPERS 47, 55–56 (2008).

74. Snow et al., *supra* note 72, at 393.

in the following section, the agency relied on the statutory drug approval framework to do so.

A. How Intentional Genomic Alterations in Animals Are Regulated

To understand and evaluate the FDA's classification of genomic alterations in animals as "drugs," it is necessary to first examine the regulatory framework and statutory foundations that led to this approach.

Scientists have pursued genetic modification in animals since the 1970s, with key breakthroughs in genome modification techniques emerging in the early 1980s.[75] Following this development, the Office of Science and Technology Policy published the 1986 Coordinated Framework.[76] The 1986 Coordinated Framework explains the regulatory roles for the USDA, the Environmental Protection Agency, and the FDA. It further directs that federal agencies should ensure public health and environmental safety while maintaining regulatory flexibility to avoid impeding the growth of the biotechnology industry.[77] The main strategy was to use current legislation to govern biotechnology, rather than new laws.[78] Given the application of biotechnology to food animals and the general strategy in the 1986 Coordinated Framework to rely on existing statutory authorities, the FDA interpreted the FDCA to assert jurisdiction over GE animals.[79] The updated Coordinated Framework from 2017 ("2017 Coordinated Framework") adopts this posture and explicitly acknowledges the

75. *See generally* Rudolf Jaenisch & Beatrice Mintz, *Simian Virus 40 DNA Sequences in DNA of Healthy Adult Mice Derived from Preimplantation Blastocysts Injected with Viral DNA*, 71 PROC. NAT'L ACAD. SCI. 1250 (1974) (reporting foreign viral DNA sequences in mice derived from DNA-injected embryos); Jon W. Gordon, George A. Scangos, Diane J. Plotkin, James A. Barbosa & Frank H. Ruddle, *Genetic Transformation of Mouse Embryos by Microinjection of Purified DNA*, 77 PROC. NAT'L ACAD. SCI. 7380 (1980) (demonstrating gene transfer into the mouse genome by microinjection into early embryos); Brinster et al., *supra* note 45 (demonstrating expression of injected genes in mice); ROYAL SOC'Y, THE USE OF GENETICALLY MODIFIED ANIMALS 5–6 (2001).

76. *See* 1986 Coordinated Framework, *supra* note 14.

77. *Id.* at 3.

78. *Id.*

79 . *Id.* at 22 ("The agency possesses extensive experience with these regulatory mechanisms and applies them to the products of biotechnological processes. In this notice, FDA proposes no new procedures or requirements for regulated industry or individuals. Rather, the administrative review of products using biotechnology is based on the intended use of each product on a case-by-case basis.").

FDA's authority to regulate GE animals,[80] while the USDA's role focuses on GE plants.[81]

Pursuant to this authority, the FDA issued a guidance document in 2009 ("2009 Guidance").[82] The FDA's subsequent final guidance documents issued in May 2024 and January 2025 revised the original guidance document.[83] The final guidance documents clarify the FDA's approach to heritable IGAs in animals and explain how its approval process under the "new animal drug" framework applies to these alterations.[84]

This regulatory framework established under the FDCA is largely structured around a central distinction between "food" and "drug."[85] This sharp distinction oversimplifies the complexity of emerging biotechnologies — particularly for GE food animals. Under current law, food products generally do not require premarket approval, while drugs face a lengthy and intensive regulatory process involving the evaluation of safety, effectiveness,[86] and distinct and more rigorous manufacturing standards.[87] The absence of a clear intermediate category leaves no regulatory space for novel products that do not fit neatly into either box. This binary system, rather than adapting to technological nuance, channels regulatory oversight toward the more stringent "drug" regulatory process, effectively pushing GE food animals into an overregulated category by default.

Indeed, the FDCA provides a broad definition of drugs.[88] Not only does it include "articles intended for use in the diagnosis, cure, mitigation, treatment, or prevention of disease in man or other animals," but it also encompasses "articles (other than food) intended to affect the structure or any function of the body of humans or other

---

80. *See* 2017 Coordinated Framework, *supra* note 15, at 18 ("FDA regulates GE animals under the new animal drug provisions of the FD&C Act and FDA's implementing regulations.").

81. *Id.* at 30 ("USDA/APHIS oversees the importation, interstate movement, and environmental release of the plants (that pose a plant pest risk) that are used for food purposes.").

82. FOOD & DRUG ADMIN., GUIDANCE FOR INDUSTRY #187: REGULATION OF GENETICALLY ENGINEERED ANIMALS CONTAINING HERITABLE RECOMBINANT DNA CONSTRUCTS 1 (2009) [hereinafter 2009 GUIDANCE].

83. GUIDANCE 187A, *supra* note 17; GUIDANCE 187B, *supra* note 18.

84. *Id.*; 21 U.S.C. § 321(v) ("The term 'new animal drug' means any drug intended for use for animals other than man, including any drug intended for use in animal feed but not including such animal feed.").

85. *See* 21 U.S.C. § 321(g)(1)(C) (expressly excluding "food" from the definition of the term "drug").

86. Margaux Birdsall, *Biopharming, Bananas and Bureaucracy: The Banana Vaccine as a Case Study for Products That Straddle the Definitional Food/Drug Divide*, 66 FOOD & DRUG L.J. 265, 266 (2011).

87. *See* 21 C.F.R. § 211 (2025) (establishing minimum good manufacturing practice requirements for drugs).

88. *See* 21 U.S.C. § 321(g)(1), *supra* note 18.

animals."[89] According to the FDA's guidance, IGAs in animals are made by developers "in order to alter the structure or function of an animal in a particular way and/or to cure, mitigate, treat, or prevent disease . . . ."[90] Thus, according to the FDA, the animal itself is not the drug; rather, it is the altered DNA within the animal that is classified as the drug.[91] The FDA has embraced this interpretation to govern GE animals, as outlined in its 2009 Guidance.[92] A revised draft guidance in 2017 clarified its scope to encompass other emerging genome alteration techniques introduced since 2009.[93] Therefore, since the alteration, not the GE animal itself, is classified as a drug, the regulation pertains to the altered DNA within the GE animal.[94] Each specific alteration is treated as a distinct new animal drug, subject to the FDA's approval requirements.[95]

A new animal drug (and the DNA alterations within it) is "deemed unsafe" prior to the FDA's approval.[96] As such, the regulations require the FDA's approval before any such new animal drugs can come to market.[97] But the FDA made exceptions for this premarket approval and has adopted a tiered approach to regulating IGAs in GE animals that includes three categories.[98]

For "Category 1" products, developers are generally not expected to consult the agency before marketing.[99] This tier includes animals of "nonfood-producing species" that are regulated by other agencies, like the USDA, or "that are raised and used in contained and controlled laboratory conditions for research."[100] For "Category 2" products, no formal approval may be required if the FDA determines that submitted data in a "prior review" demonstrate well-understood and mitigated risks.[101] For these categories, the FDA does not find that these products are "safe" according to the FDCA, but rather finds it appropriate to exercise "enforcement discretion."[102] That is, the FDA does not

89. *Id.*

90. GUIDANCE 187B, *supra* note 18, at 2.

91. *See* GUIDANCE 187A, *supra* note 17.

92. 2009 GUIDANCE, *supra* note 82, at 5–6.

93. *See* U.S. FOOD & DRUG ADMIN., DRAFT GUIDANCE FOR INDUSTRY #187: REGULATION OF INTENTIONALLY ALTERED GENOMIC DNA IN ANIMALS 3–4 (2017).

94. *See* GUIDANCE 187A, *supra* note 17, at 3–4.

95. *See id.* (noting that under certain circumstances, the FDA may consider a combination of multiple IGAs or IGAs in multiple lines or breeds of animals under a single application for approval); GUIDANCE 187B, *supra* note 18, at 3–4.

96. 21 U.S.C. § 360b(a)(1) (2021).

97. GUIDANCE 187A, *supra* note 17, at 3–4.

98. *Id.* at 4.

99. *Id.* at 5.

100. *Id.*

101. *Id.* at 5–6. The prior review includes: "[I]nformation about the methodology used to generate the IGA, characterization of the genomic sequence, and information addressing animal safety, food safety, and risk of impacts on the environment, as appropriate for the intended use of the product." *Id.* at 6.

102. *Id.* at 4–5.

enforce premarket review and other applicable requirements, but it retains the right to enforce regulation in the future.[103] Only one food product has been classified under this second tier:[104] the "slick" cattle.[105] After conducting a risk assessment, the FDA announced that it did not intend to object to the marketing of the IGA in the "slick" cattle without premarket approval.[106]

"Category 3" products undergo full review, for which developers must submit a new animal drug application ("NADA").[107] In their NADA, developers are required to provide comprehensive data attesting to the safety of genome alterations concerning the animals themselves, humans involved in handling the animals, food consumption, and environmental impact.[108] Sponsors must submit the following key types of information as a part of this process:[109]

(1) Molecular characterization of the intended genomic change;[110]

(2) Details about how the construct was assembled, its sequence, and its source;[111]

(3) Molecular characterization of the GE animal lineage, which includes information about the method used to insert the alteration into the animal and an assessment of whether the rDNA construct is stably inherited over multiple generations;[112]

(4) Phenotypic characterization, focusing on whether the alteration poses risks to humans, animals, or the

---

103. *FDA's Enforcement Discretion Policy*, U.S. FOOD & DRUG ADMIN. (Sep. 2024), https://seed.nih.gov/sites/default/files/2024-12/FDAs-Enforcement-Discretion-Policy.pdf [https://perma.cc/XGB6-DAW5].

104. *Intentional Genomic Alterations (IGAs) in Animals: Risk-Reviewed IGAs*, U.S. FOOD & DRUG ADMIN., https://www.fda.gov/animal-veterinary/intentional-genomic-alterations-igas-animals/intentional-genomic-alterations-igas-animals-risk-reviewed-igas [https://perma.cc/JB35-CQPD]; Sarah Copper, *Following the Framework: Intentional Genomic Alterations in Animals*, 18 J. FOOD L. & POL'Y 117, 132 (2022).

105. *FDA Announces Animal Biotechnology Webinar on Low-Risk Intentional Genomic Alterations in Animals for Food Use*, U.S. FOOD & DRUG ADMIN. (June 27, 2022), https://www.fda.gov/animal-veterinary/cvm-updates/fda-announces-animal-biotechnology-webinar-low-risk-intentional-genomic-alterations-animals-food-use [https://perma.cc/2W2W-P2FY] (finding that IGA genotypic and phenotypic results were also present in conventionally bred cattle).

106. *Id.*; U.S. FOOD & DRUG ADMIN., *supra* note 10, at 10.

107. *See* GUIDANCE 187A, *supra* note 17, at 4; GUIDANCE 187B, *supra* note 18, at 1–2.

108. GUIDANCE 187B, *supra* note 18, at 3, 8–9, 15.

109. *Id.* at 10.

110. *Id.* at 16.

111. *Id.*; *see also* LARISA RUDENKO, *Animal Biotechnology in the United States: The Regulation of Animal Clones and Genetically Engineered Animals*, *in* CHALLENGES FOR AGRICULTURAL RESEARCH 243, 251 (OECD ed. 2010).

112. *See* GUIDANCE 187B, *supra* note 18, at 17.

environment, along with data on the physiological status of the GE animals;[113]

(5) Durability assessment, which ensures that future GE animals of the same animal line will be equivalent to those examined in the preapproval review.[114] Where feasible, the FDA recommends gathering data on inheritance from at least two generations, preferably more;[115]

(6) Food safety check, where the FDA assesses whether the composition of edible tissues in GE products differs from, and whether GE products pose a higher allergenicity risk than, their non-GE counterparts;[116] and

(7) Characterization of the site of intentional alteration and any unintended alterations (e.g., off-target alterations, unanticipated insertions, substitutions, or deletions).[117]

Furthermore, all investigational GE animals, their littermates, surrogate dams, and products need to be disposed of through methods such as incineration, burial, or composting.[118]

This whole process spans years. Examining the only three products in the United States that went through this process illustrates its time-consuming nature. First, AquaBounty's faster-growing GE salmon took a decade to get approved.[119] Even after the FDA's first approval, AquaBounty faced many barriers. The FDA initially approved the salmon in 2015 and lifted an import alert in 2019, allowing the company to begin production and sales in the United States.[120] However, a 2020 court ruling on a legal challenge required the agency to reevaluate its environmental assessment and decision.[121] The FDA completed that review and published an amended environmental

113. *Id.* at 18.
114. *Id.* at 19.
115. *Id.*
116. *Id.* at 20.
117. *Id.*; Alison Van Eenennaam, Kevin D. Wells & James D. Murray, *Proposed U.S. Regulation of Gene-Edited Food Animals Is Not Fit for Purpose*, 3 SCI. FOOD 1, 4 (2019).
118. GUIDANCE 187B, *supra* note 18, at 6. This specific requirement is highlighted here because it underscores the economic implications of the regulatory framework, as animals that could otherwise be used for food or other purposes are instead being discarded.
119. Grossman, *supra* note 60, at 193.
120. Chris Chase, *U.S. FDA Clarifies It Has Full Jurisdiction over GE Animals, Including Fish*, SEAFOODSOURCE (May 2, 2024), https://www.seafoodsource.com/news/food-safety-health/us-fda-clarifies-it-has-full-jurisdiction-over-ge-animals-aquabounty-secures-usd-10-million-loan [https://perma.cc/3EHZ-8788].
121. Inst. for Fisheries Res. v. U.S. Food & Drug Admin., 499 F. Supp. 3d 657, 670 (N.D. Cal. 2020) (order granting in part plaintiffs' motion for summary judgment and directing the FDA to reassess environmental impacts of AquAdvantage salmon).

assessment in September 2024.[122] A few months later, however, the company announced that it was shutting down its salmon operations in the United States.[123] Second, the GalSafe pig, genetically engineered to be safe for consumption by individuals with Alpha-Gal Syndrome, was successfully developed in 2003[124] but received FDA approval more than a decade after it was submitted to the FDA.[125] Third, pigs engineered to resist infection with porcine reproductive and respiratory syndrome ("PRRS") received FDA approval following a review process of approximately six years.[126]

In comparison to the FDA, the USDA plays a small and secondary role in the oversight of animal biotechnology, focused primarily on disease prevention and ensuring the safety of meat and poultry.[127] These responsibilities do not place direct conditions or restrictions on the method by which the animal has been produced, whether it is through conventional breeding or GE, but they can place some restriction on importation and environmental release for other reasons.[128]

While there was some contention behind the scenes regarding the jurisdiction over GE food animals, with both the FDA and the USDA competing for control,[129] the FDA ultimately assumed jurisdiction. Under the 2024 FDA-USDA Memorandum of Understanding, the FDA retains authority to regulate IGAs in animals as new animal drugs through the Center for Veterinary Medicine ("CVM"), while the USDA agencies play complementary roles.[130] Upon FDA notification of an

---

122. *AquAdvantage Salmon*, U.S. FOOD & DRUG ADMIN., https://www.fda.gov/animal-veterinary/intentional-genomic-alterations-igas-animals/aquadvantage-salmon [https://perma.cc/53EV-CRUV] (see specifically "September 2024 Amended Environmental Assessment for Production of AquAdvantage Salmon").

123. AQUABOUNTY TECH, *supra* note 11.

124. Carol J. Phelps, Chihiro Koike, Todd D. Vaught, Jeremy Boone, Kevin D. Wells, Shu-Hung Chen et al., *Production of α1, 3-Galactosyltransferase-Deficient Pigs*, 299 SCIENCE 411, 411 (2003).

125. U.S. FOOD & DRUG ADMIN., *supra* note 57.

126. *See infra* Section III.B.1 for a more detailed discussion of this timeline.

127. *See* Animal Health Protection Act, 7 U.S.C. §§ 8301–8322; 21 U.S.C. §§ 601–695; 21 U.S.C. §§ 451–473; *see also* 21 U.S.C. § 601(w) (defining livestock regulated under the Federal Meat Inspection Act as amenable species, including cattle, sheep, swine, goats, horses, mules, other equines, and fish of the order Siluriformes (i.e., catfish)); Margaret Grossman, *Who Will Regulate Genetically Engineered Animals in the United States?*, 16 EUR. FOOD & FEED L. REV. 322, 326 (2021) ("To protect public health, FSIS ensures that meat and poultry products that enter commerce are not adulterated (injurious to health or unfit for human food) or misbranded (bearing false or misleading labels).").

128. Grossman, *supra* note 127, at 325–26.

129. *Id.* at 326–28 (describing how the FDA did not agree with a 2021 Memorandum of Understanding between the agencies dictated the transition of regulatory oversight over GE food animals from the FDA to the USDA).

130. Memorandum of Understanding Between the U.S. Dep't of Agric. and the U.S. Dep't of Health and Human Servs. Food & Drug Admin. Concerning Information Sharing and Regulatory Cooperation Related to Intentional Genomic Alterations in Animals Subject to

IGA in an amenable species (e.g., cattle, poultry, swine), the USDA determines whether the USDA's Food Safety and Inspection Service ("FSIS"), the USDA's Animal and Plant Health Inspection Service ("APHIS"), or the USDA's Agricultural Marketing Service ("AMS") should participate in joint consultations with the developer.[131] FSIS reviews food safety and labeling information and provides comments to the FDA.[132] APHIS notifies the FDA of any livestock health or disease concerns related to the IGA and confirms whether any permits are needed under the Animal Health Protection Act.[133] AMS coordinates with the FDA on compliance with bioengineered food disclosure rules, such as labeling.[134] For non-amenable species, the USDA assesses whether additional technical information is needed to evaluate potential livestock impacts.[135]

Therefore, the USDA remains a player in the regulatory landscape in the United States, even though its possible statutory jurisdiction over GE food animals is currently, under the 1986 and the 2017 Coordinated Frameworks, largely in abeyance.[136]

III. IMPACTS OF THE REGULATION

It is well-established that overly stringent regulation can hinder innovation, while the absence of regulation can accelerate it.[137] But not enough studies have been conducted specifically regarding GE food animals and the regulation of their approval. What exists of current research shows that regulatory processes delay the development and

USDA Jurisdiction (Apr. 18, 2024), https://www.fda.gov/about-fda/domestic-mous/mou-225-24-010 [https://perma.cc/94KU-R8EH].

131. *Id.*

132. *Id.*

133. *Id.*

134. *Id.*

135. *Id.*

136. 2017 Coordinated Framework, *supra* note 15, at 9, 22–27.

137. *See also* Parker Rogers, *Regulating the Innovators: Approval Costs and Innovation in Medical Technologies*, CATO INST. (June 14, 2023), https://www.cato.org/research-briefs-economic-policy/regulating-innovators-approval-costs-innovation-medical [https://perma.cc/S6Q8-UECV] (showing how deregulation "increase[s] the quantity and quality of new technologies" through a study measuring the impact of FDA regulation on innovation and market structure); Gregory Curfman & Rita Redberg, *Medical Devices — Balancing Regulation and Innovation*, 365 NEW ENGL. J. MED. 975, 976 (2011) (discussing the balance between safety and innovation in the context of medical devices). *See generally* Michael Pesko & Christian Saenz, Pharmaceutical Drug Regulation and Mortality: Evidence from E-cigarettes (June 6, 2025) (unpublished manuscript), https://papers.ssrn.com/sol3/papers.cfm?abstract_id=5108105 [https://perma.cc/WZA2-33LD] (finding that the unexpected judicial exemption of e–cigarettes from drug regulation "led to significant increases in innovation, as evidenced by a rise in patent applications").

implementation of GE food animals.[138] The bottleneck hindering the adoption of GE food animals in agriculture stems from the absence of timely and efficient regulatory systems.[139] Some argue the regulation stifles and creates a chilling effect on animal breeding efforts by imposing significant regulatory burdens and financial costs.[140] Indeed, the decline or stagnation in the number of U.S. laboratories involved in research on GE food animals is worrying.[141]

We must factor in the cost of not using GE food animals to benefit agriculture, consumers, and the environment, treating these lost benefits the same way as we treat risks.[142] Quantifying these lost benefits is complicated, but it has been pursued.[143] Evidence suggests that the annual economic cost of regulatory delay in the use of certain GE food products can amount to millions of dollars.[144]

However, beyond the quantification of regulatory delays, no research explores the impact of the regulations on developers or provides evidence that regulations create a chilling effect on the

138. Van Eenennaam (2013), *supra* note 28, at 10; James Murray & Elizabeth Maga, *Regulatory Dysfunction Inhibits the Development and Application of Transgenic Livestock for Use in Agriculture*, in ANIMAL BIOTECHNOLOGY 2: EMERGING BREEDING TECHNOLOGIES 149, 158 (Heiner Niemann & Christine Wrenzycki eds., 2018).

139. *See e.g.*, Murray & Maga, *supra* note 138, at 149 ("There has been a failure of the regulatory processes to effectively move forward across the world, with many countries adopting process-based regulations, rather than product-based, and some countries having no regulatory framework at all.").

140. Grossman, *supra* note 127, at 324.

141. Murray & Maga, *supra* note 138, at 155–56 ("[T]he predominant amount of work to create transgenic animals for agriculture has shifted from the developed world to Asia, with China being the site of development of the majority of new transgenic lines of animals for agriculture since 2006.").

142. Jim Murray & Elizabeth Maga, *Is There a Risk from Not Using GE Animals*?, 19 TRANSGENIC RSCH. 357, 360 (2010); S.C. Fahrenkrug, A. Blake, D.F. Carlson, T. Doran, A. Van Eenennaam, D. Faber et al., *Precision Genetics for Complex Objectives in Animal Agriculture*, 88 J. ANIMAL SCI. 2530, 2536 (2010).

143. One quantitative study aimed to assess the financial and opportunity costs linked with the delay in approving GE livestock. *See* Van Eenennaam (2021), *supra* note 28, at 453. In addition to research on GE animals, studies on GE crops, which are currently more common in the United States market than GE animals, have demonstrated robust evidence of benefits. *See* Wilhelm Klümper & Matin Qaim, *A Meta-Analysis of the Impacts of Genetically Modified Crops*, 9 PLOS ONE (2014) (estimating the impacts of GE crops on crop yield, pesticide quantity, pesticide cost, total production cost, and farmer profit); Geoffrey Barrows, Steven Sexton & David Zilberman, *Agricultural Biotechnology: The Promise and Prospects of Genetically Modified Crops*, 28 J. ECON. PERSPECT. 99, 100 (2014) (arguing that "while a number of the environmental issues with genetically engineered seeds warrant scrutiny, the accumulated experience with the first wave of agricultural biotechnology has generated considerable benefits to consumers and the environment").

144. *See also* Justus Wesseler, Richard D. Smart, Jennifer Thomson & David Zilberman, *Foregone Benefits of Important Food Crop Improvements in Sub-Saharan Africa*, 12 PLOS ONE 1, 1 (2017) ("The costs of a delay can be substantial: e.g. a one year delay in approval of the pod-borer resistant cowpea in Nigeria will cost the country about 33 million USD to 46 million USD and between 100 and 3,000 lives."). *See generally* David Zilberman & Scott Kaplan, *The Loss from Underutilizing GM Technologies*, 18 AGBIOFORUM 312 (2015) (finding that regulations that delay the introduction of the technology by just one year slow the adoption rate and are associated with substantial opportunity costs).

development of GE food animals. While previous research often assumes or asserts the existence of a chilling effect, none offers a comprehensive analysis of whether it exists and how it operates. This Part provides a comprehensive analysis of that impact, focusing on the "drug" paradigm and the regulatory system it produced.

A. Stakeholder Perceptions of the Regulatory Process

The FDA's legal interpretation, the FDA's reliance on existing legislation, and the binary distinction between "drugs" and "food" all contribute to a complex and multifaceted regulatory framework for GE food animals. While other phases in the development and commercialization of GE food animals also shape the stagnation in the industry and should be investigated, existing literature commonly attributes the limited number of market-ready products and the scarcity of FDA-approved GE food animals to the regulatory requirements.[145]

Therefore, this Article focuses particularly on the regulation, which, according to both existing literature and stakeholder perspectives, is perceived as extremely burdensome.[146] Stakeholders express significant criticism regarding FDA regulation, which appears to profoundly impact their research, efforts, and motivation concerning GE food animals in various dimensions.[147] Before delving into the main effects on stakeholders, it is essential to explain *what* about the regulation influences them.

1. Perception of Hard, Expensive, and Long Process

Most of the stakeholders interviewed for this Article pointed out that the regulatory processes as outlined in the FDA guidance are excessively rigorous, extensive, and time-consuming.[148] Three recurring issues have been brought to light: the identification of unintended alterations, the analysis of food composition, and the fees.[149]

---

145. *See*, *e.g.*, Diane Wray-Cahen, Eric Hallerman & Mark Tizard, *Global Regulatory Policies for Animal Biotechnology: Overview, Opportunities and Challenges*, 6 FRONTIERS GENOME EDITING 1, 1 (2024) ("The past failure of genetically engineered (or GM) products to reach conventional producers can largely be attributed to the high cost of meeting GMO regulatory requirements.").

146. *See infra* Section III.A.1; Van Eenennaam et al., *supra* note 117, at 3–4.

147. *See infra* Section III.B.3.

148. *See infra* Sections III.B.1 and III.B.2.

149. These difficulties seem surmountable only for companies with considerable assets, such as Genus. Clint Nesbitt, Genus's Global Director of Regulatory and External Affairs, shared how his company undertook almost the same regulatory process as peer companies for their GE food products despite FDA requirements that posed challenges. *See* Interview with Clint Nesbitt, Global Director of Regulatory and External Affairs, Genus (Feb. 14, 2024)

One of the steps the FDA expects as a part of the regulatory approval process is detailed genomic characterization of the GE animal and the detection of unintended alterations that may result from the introduction of the IGA. [150] This requirement is exceptionally challenging and burdensome. [151] The underlying reason is that any animal line naturally undergoes numerous DNA alterations each generation. [152] In a GE animal marketing application to the FDA, the genome of a GE animal is scrutinized, including all identified alterations. [153] Developers are then tasked with demonstrating that these alterations occur naturally and are safe. [154]

Developers feel that this task requires them to "prove a negative."[155] Alison Van Eenennaam, a scientist from UC Davis who conducts research on GE food animals, mentioned that developers are not provided with specific hypotheses to refute, posing a scientific challenge that forces them to engage in a "fishing expedition."[156] This process is time-consuming and costly, depending on the number of alterations and examinations required. Van Eenennaam noted:

> All I can do is say there is [a] level of mutation in the background . . . I cannot [determine for] each different new mutation whether it was me or nature . . . [T]o get in[to] the food suppl[y], you have to have a healthy animal. And beyond that, there [are] no food safety risks associated with eating a healthy animal. [157]

The FDA does not deny that this is a challenging process. However, an FDA official said that although it may not be possible to conclusively prove that a particular variant resulted from genome editing solely by identifying the alteration, the statistical odds may still support that inference. [158] In a typical generation, only "five to 50" spontaneous (de novo) mutations arise across a genome of roughly

---

[hereinafter Nesbitt Interview]. The disparity in perspectives may stem from the fact that Genus is a big company with ample resources and can allocate significant funds to this process for various reasons, including public relations. *Preliminary Results for the Year Ended 30 June 2023*, GENUS (Sep. 7, 2023), https://www.genusplc.com/media/2100/preliminary-results-fy23-final.pdf [https://perma.cc/HM5A-7EA8].

150. GUIDANCE 187B, *supra* note 18, at 16–18.

151. *See also* NAT'L ACADS. OF SCIS., ENG'G & MED., *supra* note 61, at 54.

152. *See* Interview with Alison Van Eenennaam, Researcher, Univ. of Cal., Davis (Mar. 4, 2024) [hereinafter Van Eenennaam Interview]; Interview with FDA officials (Mar. 9, 2024) [hereinafter FDA Officials Interview].

153. GUIDANCE 187B, *supra* note 18, at 16.

154. *Id.* at 16–17.

155. Van Eenennaam Interview, *supra* note 152.

156. *Id.*

157. *Id.*

158. FDA Officials Interview, *supra* note 152.

three billion base pairs; therefore, if a variant appears at a predicted off-target site, there is "a reasonable likelihood" that it resulted from the genome editing process, even if it cannot be established with complete certainty.[159]

The FDA deems that this step is necessary.[160] While this step is to ensure the absence of detrimental unintended effects, the FDA asserts that even minor alterations, regardless of their origin, can lead to unforeseen and adverse outcomes.[161] To mitigate such risks, the FDA underscores the importance of confirming that IGAs in animals do not inadvertently compromise food safety.[162] Consequently, this approach is deemed risk-based, as the FDA evaluates potential hazards and assesses the likelihood of harm throughout the process.[163] The FDA recognizes that not all alterations pose risk issues.[164] Statistically, many of these alterations are not critical from a safety standpoint.[165] Nonetheless, the FDA asserts that these alterations should be examined due to chance that they may lead to unintended consequences.[166]

Another step widely considered by stakeholders as extremely challenging is food composition analysis. As part of this evaluation, developers demonstrate the equivalence of GE food animals to their non-GE counterparts.[167] This presents significant difficulties. Food composition changes throughout an animal's life cycle and is influenced by various factors such as diet, environment, health, and other variables.[168] There are no standardized characteristics that a GE food product must meet. For instance, there are no established standards for proteins, allergens, or other components in the food that developers must adhere to.[169] Hence, developers must create their own

159. *Id.*

160. *Id.*; Epstein et al., *supra* note 64, at 2 (asserting that "[b]oth phenotypic and genotypic characterization of IGAs and their potential unintended effects are important because genetic changes can impact safety"); *see also* Steven M. Solomon, *Genome Editing in Animals: Why FDA Regulation Matters*, 38 NATURE BIOTECH. 142, 142–43 (2020) (FDA scientists presenting how "[their] analysis illustrates . . . why it is necessary for there to be regulatory oversight of IGAs in animals, even when the intended modification seeks to replicate a naturally occurring mutation").

161. *See* Solomon, *supra* note 160, at 142–43.

162. *Id.* ("The FDA also wants to ensure these alterations do not affect food safety. Unintended alterations may affect protein expression, including the disruption of protein function, changes to the expression level of a protein (such as the overexpression of a hormone receptor), or the creation of a new expression product.").

163. RUDENKO, *supra* note 111, at 250. Dr. Rudenko was in the FDA during the formation of these regulations, and she was identified in the 2009 Guidance as the point of contact for inquiries regarding the document. 2009 GUIDANCE, *supra* note 82, at 1.

164. GUIDANCE 187A, *supra* note 17, at 5–6.

165. *See* Van Eenennaam Interview, *supra* note 152, at 4–5; *see also* FDA Officials Interview, *supra* note 152.

166. *See* FDA Officials Interview, *supra* note 152.

167. GUIDANCE 187B, *supra* note 18, at 20.

168. NAT'L ACADS. OF SCIS., ENG'G & MED., *supra* note 61, at 56–62.

169. *Id.*

benchmarks and compare GE food animals to their non-GE counterparts to determine equivalence. Eric Hallerman, a researcher from Virginia Tech, explained:

> You open a whole new can of worms with [food composition]. [T]hings that have traditionally been in the food supply [have never been analyzed] very much. If you analyze milk from a particular cow, [the composition] will vary depending upon her age, whether [it] is a first or subsequent birth, how far she is in the lactation period, her state of nutrition, and her health. Similarly, [meat quality of] different animals from the same breed at the same facility will vary. [W]e do not have much data about that. . . . It is a chaotic system.[170]

How challenging this step is depends also upon the animal in question. Hallerman illustrated this consideration as the following:

> If it is salmon . . . it is a lot of lab work, but it will be tens of thousands, maybe a couple of hundred thousand dollars [to satisfy this requirement]. If it is beef, raising forty animals, slaughtering them, and [not being able to] sell the meat [during the development process before the FDA's approval] is a problem [for developers].[171]

Another issue is fees.[172] The fees imposed by the FDA are substantial, reaching hundreds of thousands of dollars annually, which can prove extremely difficult for small companies to afford.[173] And because commercialization of GE food animals may take years, cumulative user fees over the course of the regulatory process can plausibly reach into millions of dollars, increasing the total costs that the eventual product must recoup in order to be profitable. Although this issue was raised by certain stakeholders, there are exceptions to these fee requirements such that the fees do not affect every potential

---

170. Interview with Eric Hallerman, Researcher, Va. Tech. (Feb. 22, 2024) [hereinafter Hallerman Interview].

171. *Id.*

172. *See, e.g.*, Interview with Jon Oatley, Researcher, Wash. State Univ. (Feb 23, 2024) [hereinafter Oatley Interview]; Interview with Tad Sonstegard, Chief Sci. Officer, Acceligen (Feb. 23, 2024) [hereinafter Sonstegard Interview].

173. *See* Animal Drug User Fee Act (ADUFA), 21 U.S.C. §§ 379j-11 to 379j-15; *Animal Drug User Fee Act (ADUFA)*, U.S. FOOD & DRUG ADMIN. (Nov. 13, 2025), https://www.fda.gov/industry/fda-user-fee-programs/animal-drug-user-fee-act-adufa [https://perma.cc/7FU7-3LTU] (listing updated user fee amounts).

or current stakeholder and may present a barrier only in specific cases.[174] Specifically, the fees do affect larger companies that do not fall into an exception, potentially impacting the profitability of their projects. For example, Genus likely incurred substantial FDA user fees in connection with its PRRS-resistant pig approval. However, although Genus reportedly invested tens of millions of dollars in developing the product,[175] its annual FDA fees — often reaching hundreds of thousands of dollars[176] — may not represent the primary cost driver due to its deeper pockets.[177] Nevertheless, these annual FDA fees impose a meaningful additional financial burden for other players with fewer resources.

2. Uncertainty in the Regulatory Process

Some stakeholders also characterize the regulatory process as uncertain, noting that it is not just the difficulty, expense, and length of certain requirements that pose challenges, but also the ambiguity surrounding FDA expectations. There is uncertainty about whether the FDA will find the data provided satisfactory, what additional information the FDA may request during the process, and whether it will ultimately approve the product. As noted by Diane Wray-Cahen, a former official from the USDA Office of the Chief Scientist, "the breeding companies do not want to devote their money towards something they do not know how long it is going to take and what the outcomes are going to be."[178]

The FDA conducts a "rolling review" process in reviewing applications for drug approval. This process allows developers to submit completed technical sections of their New Animal Drug Application for review by the FDA, as they are completed, rather than waiting until every section of the application is completed before

174. U.S. FOOD & DRUG ADMIN., REVISED GUIDANCE FOR INDUSTRY #170: ANIMAL DRUG USER FEES AND FEE WAIVERS AND REDUCTIONS 4–8 (2023) (describing cases in which fee waivers are applicable, including when fee will exceed profit, cases of minor species, and "small businesses").

175. *See* GENUS, *supra* note 11.

176. *See FDA Announces FY2025 Animal Drug User Fee Rates*, U.S. FOOD & DRUG ADMIN. (July 31, 2024), https://www.fda.gov/animal-veterinary/cvm-updates/fda-announces-fy-2025-animal-drug-user-fee-rates-adufa-and-agdufa [https://perma.cc/3KJ6-VP6L] (listing fee amounts under the Animal Drug User Fee Act ("ADUFA") V and noting animal drug application fee of $581,735, supplement fee of $290,867, product fee of $10,705, establishment fee of $157,702, and sponsor fee of $137,446).

177. *See supra* note 149.

178. Interview with Diane Wray-Cahen, Former Senior Advisor for Animal Health and Production, and Animals Products, U.S. Dep't Agric. (Mar. 9, 2024) [hereinafter Wray-Cahen Interview]. Wray-Cahen held this position at the time of the interview but has since left. All the views expressed are her own and should not be attributed to the USDA.

submitting for review.[179] The FDA offers two rationales for its approach. First, the rolling method assists developers in submitting data and information in support of technical sections of the application, potentially expediting the process.[180] Second, the FDA believes this approach is important due to their "risk-based process." The FDA maintains that fulfilling its obligation to ensure product safety requires evaluating each GE animal line on a case-by-case basis, which in turn necessitates a rolling review process.[181]

There are, however, challenges associated with this approach, as the FDA acknowledges:

> [The case-specific nature of the review] makes [regulatory] guidance challenging because [the FDA] do[es] not have the ability to just say, "Here is a list of 10 items that you need to give us" . . . [B]ecause the risk questions are . . . product-specific, [the FDA] think[s] that [a prescriptive approach] is not actually beneficial to the stakeholders.[182]

Wray-Cahen highlights that the FDA's rolling approval process introduces a great deal of uncertainty from an animal breeding perspective.[183] Because each technical section is reviewed independently, developers are unable to rely on a fixed or clearly sequenced set of requirements. Instead, the FDA's feedback at each stage may influence the scope and content of subsequent submissions, creating a dynamic and evolving review process. This interdependence between stages makes it difficult for developers to anticipate what additional data, studies, or analyses may be required as the application progresses. As a result, developers need to continuously adjust their research and data-generation strategies in response to shifting regulatory expectations. This uncertainty extends not only to the content of the requirements but also to the timing of approval. Because the scope of review is not fully defined at the outset and may expand over time, developers face considerable difficulty in predicting the overall duration of the process.

This lack of predictability is compounded by the scarcity of products that have successfully navigated the regulatory pathway,

---

179. *Fast Track*, U.S. FOOD & DRUG ADMIN. (Aug. 13, 2024), https://www.fda.gov/patients/fast-track-breakthrough-therapy-accelerated-approval-priority-review/fast-track [https://perma.cc/LBX6-BJ9D].

180. GUIDANCE 187B, *supra* note 18, at 15; *see* also FDA Officials Interview, *supra* note 152.

181. GUIDANCE 187B, *supra* note 18, at 17; *see* also FDA Officials Interview, *supra* note 152.

182. FDA Officials Interview, *supra* note 152.

183. *Id.*

leaving few real-world examples from which future applicants can learn. And the few products that have been approved, like AquAdvantage salmon, illustrate just how lengthy and unpredictable the process can be, further deepening the uncertainty for future sponsors.[184] Although the FDA's guidance sets forth general categories of required information, the FDA provides limited direction as to how those requirements will be applied in individual cases or how evidentiary expectations may vary across products. Such variability creates substantial regulatory uncertainty for developers.

As discussed below, this uncertainty stems in part from the FDA's reliance on the animal drug approval framework, which imposes a comprehensive review structure but does not provide clear, standardized pathways for different categories of products. Within this rigid statutory framework, the agency attempts to adjust its requirements on a case-by-case basis, but it lacks sufficiently flexible regulatory tools to differentiate meaningfully between higher- and lower-risk products. As a result, although the FDA's approach is defensible within the constraints of the current statutory regime, it ultimately reflects a structural limitation: the system relies on a single, intensive approval pathway rather than a tiered model with calibrated levels of oversight and clearer, more predictable requirements.

3. (Lack of) Compatibility to the Food Industry

Stakeholders also pointed to the incompatibility of the new drug approval process in regulating GE food animal. As Wray-Cahen stated, the drug paradigm is "not a good paradigm for regulating animal breeding" because the agriculture market is a "totally different kind of market" that is "not a drug market," and breeding is "not drug production."[185] The FDCA's drug framework was not designed with agricultural biotechnology in mind and is ill-suited to govern the development of GE food animals.

The first example of this lack of compatibility concerns the facilities inspection conducted by the FDA for drug production. Because the altered DNA in the GE food animal is classified as a drug, the FDA needs to inspect the facilities used for production.[186] In our case, this includes the facilities where breeders raise their GE food animals. Even after the FDA approves the GE food animal and it is sold

184 . *See supra* Section II.A (detailing the twenty-year regulatory odyssey of the AquAdvantage salmon).

185. Wray-Cahen Interview, *supra* note 178.

186. *See Pharmaceutical Inspections and Compliance*, U.S. FOOD & DRUG ADMIN. (Dec. 5, 2024), https://www.fda.gov/drugs/guidance-compliance-regulatory-information/pharmaceutical-inspections-and-compliance [https://perma.cc/W24C-8TSP].

and consumed, every existing facility as well as every new facility must undergo FDA approval for drug production.[187]

This process poses challenges. Mark Walton, former Head of Regulatory Affairs at AquaBounty, shared the inspection process for AquaBounty's facilities used to breed GE salmon and the FDA's process for determining whether these facilities are in compliance as "drug manufacturing facilities."[188] Walton emphasized that this issue is not exclusive to the GE fish industry but extends to other animals like cattle, explaining that the process of "tak[ing] a barn and call[ing] it a drug manufacturing facility" is strange and unsuitable for agriculture.[189] After all, FDA examiners, while expert in drug facility protocols, typically possess little knowledge of commercial fish production. This creates a risk of context-blind enforcement, where an inspector might cite a facility for non-compliance over issues like ceiling rust. While such environmental factors are disqualifying in a true drug facility, they are immaterial in the context of aquaculture farming, where equipment is continuously exposed to water and outdoor conditions, rather than a controlled manufacturing environment governed by sterile standards.

Another example is the FDA's call for information regarding the durability of genotype and phenotype.[190] The FDA recommends that the sponsor include information demonstrating the durability of the genotype and phenotype (i.e., whether the IGA is stably inherited and the phenotype is consistent and predictable across generations). This expectation essentially calls for consistency of the whole phenotype over time.[191] According to FDA guidance, changes in phenotype — *even if unrelated to the genomic alteration* — may harm the durability assessment. For instance, crossbreeding with another animal line that alters the phenotype, even if the genomic edit itself remains intact, could be viewed as compromising the FDA's expectations of stability.[192]

---

187. *See id.*

188. Interview with Mark Walton, Former Head of Regulatory Affairs, AquaBounty (Mar. 4, 2024).

189. *Id.*

190. GUIDANCE 187B, *supra* note 18, at 19–20.

191. *Id*.

192. *Id.* ("Your durability plan should include validated genotypic and phenotypic durability methods. The genotypic durability method is a method of identity with sufficient discrimination to determine (1) whether a given animal contains the IGA, and (2) whether the IGA has significantly changed from that which was evaluated to be safe and effective (i.e., a detection method for your IGA in its final stabilized genomic location(s) in the animal). The phenotypic durability method is a method that evaluates whether the intended phenotype was achieved (e.g., if an introduced protein is expressed or if a deletion has resulted in the absence or truncation of an expression product as intended). The amount of change considered significant could vary based on the type of IGA but, in general, significance is determined by

This durability assessment is a clear misfit with the agricultural industry. As Wray-Cahen pointed out:

> There [are] a number of [drug approval requirements], including durability, that really just do not make sense . . . . From an [agricultural] animal breeding standpoint you are always hoping [that] the next generation is going to be better. [Animal breeders] actually want [] the next generation not to be the same, but [t]o be different. You are constantly introducing new animals and breeding them [to] improve [] production. [Agricultural animal breeding] is not [intended] to keep a level playing field.[193]

The durability assessment effectively pressures breeders to maintain a highly consistent animal line, limiting conventional breeding practices and potentially slowing innovation. The result is a regulatory expectation that discourages natural genetic diversity and improvement efforts in favor of phenotypic uniformity, reflecting a mismatch between regulatory goals and agricultural realities.

While this requirement may seem reasonable in the context of drugs, it poses significant challenges to agricultural progress. It restricts breeders from utilizing selective breeding, while conventional breeders continue to achieve cumulative genetic gains across generations. Wray-Cahen highlights the opportunity costs associated with the FDA's durability assessment:

> [With] every generation, you are trying to improve the animal. If you try to freeze the genetics of these animals, as you are trying to do the studies [for the durability requirement], the rest of the world is continuing to breed better and better animals. [But] you want to make sure that you have increased [genetic] improvement over time. Losing a generation of improvement is a lot. And if you have to [lose genetic improvements associated with] multiple[] [generations of animals,] [the loss in opportunity costs] is much more, if you think about how long a generation time is [for livestock].[194]

---

whether the change impacts the safety or effectiveness of the IGA. One example of significant change would be any change that leads to an altered phenotype (as identified via the phenotypic durability method).").

193. Wray-Cahen Interview, *supra* note 178.

194. *Id.*

This places genetic engineering breeders at a disadvantage, as they must prioritize regulatory compliance and phenotypic consistency, while their competitors continue to achieve cumulative genetic gains. Consequently, the drug-centric framework ensures that by the time a GE food animal receives approval, its underlying genetics may already lag behind the industry standard.

B. The Practical Effects on Stakeholders and the Industry

These factors affect stakeholders and the industry in two primary ways. First, this approach to regulation significantly reduces the number of players, companies, and individuals involved in these projects, resulting in a relatively small industry. Second, even among those who do engage with this technology, there is less variety of genome alterations and new traits for food animals.

1. Reduction in Players

Regulation played a significant role in fostering an environment in which companies hesitate to engage with GE food animals. Key deterrents include limited access to funding (e.g., by venture capital), uncertainty, and a regulatory process perceived as arduous, expensive, and time-consuming.

Based on discussions with various individuals, the regulation itself has a significant — perhaps the most significant — impact on the funding of GE food animal projects and the companies interested in pursuing them. The scarcity of small companies and start-ups in the industry indicates a landscape fraught with challenges. A closer look at these small companies sheds light on how regulatory pressures shape their product and business strategy. The difficulty in securing capital for these companies makes their existence exceedingly challenging, which explains their scarcity.

Acceligen is a small breeding company that uses genetic engineering to enhance food animals and likely the only small company publicly engaged in GE food animal development.[195] At the time of the interview with its Chief Science Officer, Tad Sonstegard, Acceligen was developing polled (hornless) cattle, and the FDA had previously exercised "enforcement discretion" for the company's short-slick cattle.[196] The company has encountered significant challenges in

195. Sonstegard Interview, *supra* note 172 (describing the scarcity of other start-ups operating in the GE food animal development space and explaining that development efforts appear largely limited to large companies, with the scarcity of start-ups driven by the difficulty of securing funding as well as the burdens and uncertainty associated with the regulatory process).

196. U.S. FOOD & DRUG ADMIN., *supra* note 10, at 5, 10.

securing capital for its projects. Sonstegard has invested heavily in traveling around the United States and advocating for the company's technology with breeders and investors. He has found that breeders and farmers "were pretty accepting of the [company's] idea"; in contrast, "[investors] — were not."[197] Based on his experience, the most prevalent reason for investors to decline investing was the regulatory path that these products needed to travel to come to market in the United States. In fact, investors expressed concerns due to Acceligen being an American company subject to FDA approval, which they saw as a "roadblock to getting a return on their investment because of the uncertainty in the regulatory system."[198]

Sonstegard also explained how capital from investors is critical for small companies and startups that rely on investors "to stay alive as a startup."[199] Funding from individuals, termed angel investors, enabled Acceligen to provide sufficient data for the FDA to exercise enforcement discretion for their slick cattle. However, Sonstegard shared that after this decision that put Acceligen's slick cattle in the market, "there was a lot of inquiries [from investors on] if the rules were changing and things are getting easier . . . [But] in general venture capitalists stay away from [Acceligen]."[200] Acceligen's experience sheds light onto the investors' reluctance to invest in uncertain prospects and underscores the significance of regulations contributing to that uncertainty in their decision-making process regarding investments in GE food animals.[201] As Sonstegard has characterized, "if you cannot get through [the] FDA . . . then you are never going to get an investment. So whether [the] FDA likes it or not, they have made a climate that is negative for investors to put money into startup companies that are trying to bring this technology into a commercial space."[202]

Revivicor is another example of a small company involved in GE food animals. Although Revivicor was acquired by United

197. Sonstegard Interview, *supra* note 172.

198. *Id.*

199. *Id.*

200. *Id.*

201. This dynamic extends beyond GE food animals to the broader biotechnology sector. Surveys of biotech CEOs indicate concerns that investors are shifting toward other industries due to regulatory uncertainty and burdensome approval processes. Meagan Parrish, *Biotech CEO Confidence Hits Rock Bottom amid Policy Shifts*, PHARMAVOICE (June 4, 2025), https://www.pharmavoice.com/news/biotech-ceo-confidence-market-investment-vc-incubate-trump-ira/749776 [https://perma.cc/GZL8-8AQY]; *see also* Stuart J. Smyth, Jillian McDonald & Jose Falck-Zepeda, *Investment, Regulation, and Uncertainty: Managing New Plant Breeding Techniques*, 5 GM CROPS & FOOD 44, 49 (2014) ("A factor further complicating the investment decisions of agricultural biotechnology firms is the effects of regulation and time delays in the approval process. The uncertainty of these time delays affects the investment decisions of the firms.").

202. Sonstegard Interview, *supra* note 172.

Therapeutics in 2011[203] — and therefore can no longer be characterized as a small company — it began its work in this area prior to becoming part of a larger corporate entity and has one of the only three products that were approved after undergoing the full FDA regulatory process.[204] However, while Revivicor was a small company that successfully navigated the FDA regulatory process and secured funding, its experience is not representative of the challenges faced by small agricultural biotechnology companies. The GalSafe pig, approved for human consumption by the FDA, was initially developed for xenotransplantation, (transplantation, implantation, or infusion of tissue or cells into a human recipient).[205] As Revivicor pursued this biomedical application, it began receiving inquiries from individuals about whether its pigs could also be sold for food.[206] This interest stemmed from the fact that the GalSafe Pig also provided a solution for individuals who cannot consume pork due to Alpha-Gal Syndrome.[207] Thus, Revivicor's success was closely tied to its biomedical mission. The company's genetically engineered pigs were developed primarily for medical applications, and their approval for human consumption was largely ancillary to that broader therapeutic purpose.[208] In other words, Revivicor was able to leverage funding and institutional support driven by biomedical priorities rather than agricultural markets. Moreover, following its acquisition by United Therapeutics, Revivicor benefited from the financial backing and regulatory capacity of a well-resourced parent company — advantages that most small agricultural start-ups do not possess.

Another important factor for companies and investors is the time from development to market. While it is commonly believed that the AquAdvantage salmon and GalSafe pig took a long time to gain FDA approval (e.g., twenty years for the AquAdvantage salmon), this perception is misleading.[209] According to current and former FDA officials, those timeframes often include years before any formal regulatory review began — such as when a file was first opened during product development. The actual regulatory process for NADA and

---

203. *United Therapeutics Corporation History*, UNITED THERAPEUTICS (2026), https://www.unither.com/about-us/history [https://perma.cc/GFX2-ABFL].

204. *See* NATURE BIOTECH., *supra* note 11.

205. U.S. FOOD & DRUG ADMIN., *supra* note 57.

206. Lauren Neergaard, *Pig Transplant Research Yields a Surprise: Bacon Safe for Some People Allergic to Red Meat*, KSL.COM (July 22, 2024), https://www.ksl.com/article/51074577/pig-transplant-research-yields-a-surprise-bacon-safe-for-some-people-allergic-to-red-meat [https://perma.cc/5G69-B3CY].

207. U.S. FOOD & DRUG ADMIN., *supra* note 57.

208. Revivicor is a biotechnology company specializing in gene editing of pigs to make their organs suitable for human transplantation. Revivicor has succeeded in their medical project on xenotransplantation, with some promising results. *See First Gene-Edited Pig Kidney Transplant*, 42 NATURE BIOTECH. 543, 543 (2024).

209. *See* Grossman, *supra* note 127, at 323.

premarket approval was shorter, closer to eight to ten years for each. This includes not only the time spent on actual FDA review, but also the time spent to provide the data that the FDA requires.[210]

These timelines are nonetheless lengthy. For investors, a decade-long approval is still a significant hurdle. The only exception is Genus's PRRS-resistant pigs, which received FDA approval in April 2025 after a review process of approximately six years.[211] This marks a notable acceleration compared to earlier cases like the salmon. The reasons for this shift are not entirely clear. It is less likely that the FDA has relaxed its standards, particularly in light of the updated guidance it released in January 2025.[212] One reason for this acceleration may be Genus's substantial resources and regulatory expertise that helped expedite the process,[213] or perhaps the fact that the AquaBounty's experience informed Genus in this newer approval process.[214] In addition, large companies like Genus have their own funding and are not as impeded by the lack of investors.[215] In fact, Genus has invested substantial resources in bringing its PRRS-resistant pigs toward commercialization, spending millions of dollars on the project and regulatory process.[216]

However, there are very few large companies in the GE food animal space. The high cost, lengthy timelines, and regulatory uncertainty may deter even well-capitalized firms from entering the market. Aside from Genus, no major company has pursued the development of GE food animals, likely because they do not see it as commercially worthwhile.[217] This effect of regulation on big

---

210. FDA Officials Interview, *supra* note 152.

211. NATURE BIOTECH., *supra* note 11, at 839. This development stems from research published in 2016, but according to Clint Nesbitt, they started working with the FDA around 2019. *See* Van Eenennaam et al., *supra* note 117, at 4; Nesbitt Interview, *supra* note 149.

212. GUIDANCE 187B, *supra* note 18.

213. *See Genus plc (GNS.L)*, YAHOO! FIN., https://finance.yahoo.com/quote/GNS.L/ [https://perma.cc/EL5U-M4NA] (stating Genus's market capitalization at over 1.6 billion dollars as of April 2026).

214. AquaBounty was the first company to obtain approval for a GE food animal, and much of its regulatory process is documented in FDA materials, providing a concrete example of how the agency applies its requirements in practice. *See* U.S. FOOD & DRUG ADMIN., *supra* note 122.

215. *See Reports and Presentations*, GENUS, https://www.genusplc.com/investors/results-reports-and-presentations/ [https://perma.cc/CX2E-5496] (indicating Genus's funding for research and regulatory processes per its annual reports for FY2024 and FY2025).

216. *See* GENUS, *supra* note 11, at 26 (showing millions of dollars spent to achieve regulatory approval by the FDA according to Genus's 2025 interim results). Note, that the expenses are mostly for regulatory reasons, as the technology was already developed in 2016. *See* NATURE BIOTECH., *supra* note 11 ("The work stems from the research of Randall Prather at the University of Missouri, who published in *Nature Biotechnology* in 2016.").

217. The author was unable to identify any major company — aside from Genus — that has engaged in GE food animal research over the past five years. This perception was echoed by interviewees for this article, none of whom were aware of any other company conducting such work. Given the small size of the industry, the most likely explanation is that no such company currently exists.

companies and their reluctance to invest in Research and Development is evident in other industries as well,[218] and may be considered like an implicit tax.[219]

The information received from the USDA and the FDA further supports the conclusion that there is little incentive to pursue these projects. When asked about the status of GE food animal applications, an FDA official responded that the FDA "cannot give . . . specifics [about GE food animal applications], but in general . . . [t]here are not a lot [of GE food animal applications]. So this idea that [the FDA is] kind of sitting on all these applications, and [that the applications] are not out there because of [the FDA] . . . is not accurate."[220] Indeed, it appears that the issue lies not in the regulatory process once an application has been submitted, but in the impact of the regulatory framework on the decision-making process of academics and the industry in choosing whether to pursue these projects.[221]

Wray-Cahen believes that the regulatory framework has a significant impact on the development landscape, drawing a parallel with the GE plants industry. She believes "[the] FDA would like to say that it had no impact on the development [of GE food animals], but . . . the evidence is very strong that that is not the case, not only on the animal side but also on the plant side."[222] She cited Argentina as a case study since it has changed its regulations, recently categorizing some gene editing outcomes as conventional products. Consequently, some products are treated the same as those derived from conventional breeding, requiring no additional regulatory process:

> What [Argentina] saw [before adopting their new regulatory approach, is that] 90% of their initial approvals were [of products from] huge, large biotech companies, and there were no animals[, only crops]. [However, after the regulatory change], 25% of their applications were for animals, and now, only 10% of their applications are from the large biotech [companies, with the rest] from smaller companies and from academic[s] . . . . The change in the

218. Betsy Vereckey, *Does Regulation Hurt Innovation? This Study Says Yes*, MIT SLOAN (June 7, 2023), https://mitsloan.mit.edu/ideas-made-to-matter/does-regulation-hurt-innovation-study-says-yes [https://perma.cc/X9JJ-WFJ3] (finding firms are less likely to innovate if increasing their head count leads to additional regulation).

219. Philippe Aghion, Antonin Bergeaud & John Van Reenen, *The Impact of Regulation on Innovation*, 113 AM. ECON. REV. 2894, 2898 (2023).

220. FDA Officials Interview, *supra* note 152.

221. This assertion is supported by the fact that, as the FDA has acknowledged, there are likely few applications pending before the agency. The scarcity of both new developments and regulatory submissions suggests that large-scale research in this area is minimal, with only a handful of active projects underway.

222. Wray-Cahen Interview, *supra* note 178.

> percentages [is] due to an increase in applications from small companies and academics; the number of applications from large corporations did not fall.[223]

Other research also supports this proposition,[224] indicating that the regulatory framework governing GE food animals has a significant influence on which actors enter the market and how many of them do so.

2. Reduction in Trait Diversity

Apart from the lack of funding and motivation to pursue their animal biotechnology projects in general, the regulation directly affects the way small companies operate in the United States in several other ways. Small companies adapt their products to increase their chances of successfully navigating the regulatory process. FDA regulations create incentives for developers to focus on genome alterations that they believe would have a smoother approval process. Acceligen's Tad Sonstegard mentioned that their research is specifically aimed at genomic alterations for which the FDA is likely to exercise enforcement discretion.[225] Sonstegard noted that while the process of

---

223. *Id.*

224. María Florencia Goberna, Augustina Inés, Perla Godoy & Dalia Marcela Lewi, *Genomic Editing: The Evolution in Regulatory Management Accompanying Scientific Progress*, FRONTIERS BIOENG'G & BIOTECH., Feb. 2022, at 1 (showing that the speed of innovation of these technologies was increasing in Argentina, giving more opportunity to local developers who showed interest in generating products involving different species and phenotypes); Gabriella Garrappa, *Argentine Milestones in Animal Biotechnology: Advantages of a Good Regulatory Approach*, Powerpoint Presentation at the 4th International Workshop on Regulatory Approaches for Agricultural Applications of Animal Biotechnologies, ISAAA (Sep. 12–16, 2022), https://www.isaaa.org/kc/proceedings/animalbiotechnology/2022-09-12-4th-intl-workshop/session06/36Garrappa/default.asp [https://perma.cc/LQ82-HTWL] (discussing the advantages of the Argentine regulatory framework, including increased availability of information, reduced uncertainty among both developers and users, facilitation of the decision-making process and diffusion of innovation, and more predictable regulatory costs for innovative products). *See generally* Agustina I. Whelan, Patricia Gutti & Martin A. Lema, *Gene Editing Regulation and Innovation Economics*, FRONTIERS BIOENG'G. & BIOTECH., Apr. 2020 (demonstrating that the relatively lenient regulatory approach adopted in Argentina is already promoting innovation, with noticeable changes including an increase of developers and the diversification of products and much more GE food animals research and developments).

225. As emphasized in the regulatory background, GE animals generally undergo premarket approval by the FDA. Nevertheless, the FDA allows exceptions, such as through exercising enforcement discretion. *See supra* Section II.A. Acceligen made the strategic decision not to pursue traits that would likely trigger the full process of new animal drug approval. Instead, they focus solely on genomic alterations that occur naturally, increasing their chances of qualifying for the enforcement discretion option. Currently, they are working on developing a new trait in cattle, specifically the polled ("hornless") characteristic, which exists in nature. However, they are intentionally inducing these genomic alterations rather than relying solely on conventional breeding methods, which can be time-consuming and less precise. *See* Sonstegard Interview, *supra* note 172.

providing the data required for the FDA to exercise enforcement discretion is still laborious, as it requires extensive explanations of animal agriculture processes and the conduct of substantial genome sequencing, it is less arduous than the full regulatory process, and hence much more feasible for them as a small company.[226] Therefore, projects such as hornless cattle pursued by Acceligen are likely to follow a similar path, as they involve replicating naturally occurring mutations rather than introducing entirely new traits. This approach aligns more closely with the criteria for the FDA to exercise enforcement discretion, making it a more feasible option for the company. For the same reason, some companies like Acceligen prefer to operate outside the United States and pursue GE food animal projects in other countries where the regulatory process is much more lenient.[227] In cases where Acceligen does not believe that a product would appropriately be considered a Category 2 product, for which the FDA may exercise a policy of enforcement discretion, Acceligen pursues projects abroad, specifically in Brazil and Argentina, where it perceives the regulatory environment to be more favorable.[228] Furthermore, changes in regulation have occurred in Nigeria, Kenya, and Malawi, prompting Acceligen to consider expanding its operations to these countries as well.

Comparative evidence from Argentina — where a more permissive regulatory framework has been associated with an increase in the number of developers and a diversification of products — illustrates how regulatory design can shape innovation.[229] In contrast, the United

---

226. Sonstegard Interview, *supra* note 172.

227. Acceligen, for example, works outside of the United States, specifically in Latin America, because they believe the regulation there is more certain and easier. *Id.* Although not a perfect example as it does not pertain to food per se, the GE milk goats developed by UC Davis also illustrate the shift of products from the United States to other countries. *See, e.g.*, *Super Goats To Fight Third-World Diseases*, NBC4 WASHINGTON (last updated Apr. 7, 2009, at 20:20 ET), https://www.nbcwashington.com/news/health/super-goats-to-fight-third-world-diseases/1888756/ [https://perma.cc/FQ8S-4SKG]; *see also Murray & Maga Improve Goat Milk with Genetic Engineering*, (July 9, 2018), https://animalscience.ucdavis.edu/news/murray-maga-improve-goat-milk-genetic-engineering [https://perma.cc/NJ6M-C5XC]. Elizabeth Maga and Jim Murray introduced a human gene into the goat genome to enhance the production of lysozyme in goats' milk. The aim was to potentially utilize milk to combat life-threatening diarrhea in weaned children in developing nations. They attempted to bring this product to market in the United States but faced difficulties due to the regulatory system. They were unable to find a company willing to navigate the regulatory process for this product. As a result, they shifted development to Brazil, where a more favorable and predictable regulatory environment made further advancement feasible. Hallerman Interview, *supra* note 170.

228. Sonstegard Interview, *supra* note 172. For more details on the regulation in Brazil and Argentina, *see infra* Section V.D.

229. *See* Whelan et al. *supra* note 224, at 7 ("According to the preliminary evidence presented here, the regulatory approach adopted in Argentina is already stimulating local innovation processes. Noticeable changes include an increase of technology developers/providers and the diversification of products.").

States framework may not only limit participation by smaller firms but also narrow the range of traits pursued, as developers concentrate on projects most likely to survive regulatory scrutiny. Taken together, these effects suggest that regulation does not merely slow innovation but redirects it — both geographically and substantively.

3. Effects on Academics

> I CAN ONLY AFFORD EITHER A GRAD STUDENT OR AN INCINERATED COW. WHAT DO I WANT TO PAY FOR?[230]

There is a considerable amount of frustration among academics that further constrains beneficial innovation. Alison Van Eenennaam of UC Davis is a scientist who conducts research on GE food animals, particularly cattle. She expressed deep frustration with the regulatory process and is considering shutting down her lab.[231] This sentiment of frustration and challenge is echoed by other academics, such as Eric Hallerman and Jon Oatley from Washington State University. Oatley remarked: "We get frustrated because we do not always see a path by which we can get our science out of our laboratories into actually having public impact. And that's a big challenge."[232]

Regulation impacts their research in several ways. First, following their research, academics are encouraged to incinerate, bury, or compost all investigational animals used.[233] They cannot sell their investigational animals to recoup some of the expenses without FDA approval,[234] which significantly limits their research.[235] Van Eenennaam noted that this limitation affects what she can afford in her research, expressing frustration with funding constraints that limit other projects and ideas she would have liked to work on.[236] The FDA does offer a process to approve the sale and consumption of these investigational animals. However, the regulations, some of which resemble the FDA drug approval process, are stringent. As a result, as Van Eenennaam explained, the FDA's request "was so expensive to

230. Interview with Alison Van Eenennaam, Researcher, Univ. of Cal., Davis (Jan. 10, 2024).

231. Van Eenennaam Interview, *supra* note 152.

232. Oatley Interview, *supra* note 172.

233. GUIDANCE 187B, *supra* note 18, at 6.

234. *Id.* ("Introducing treated investigational animals or animal products into the food supply requires an Investigational Food-Use Authorization (21 CFR 511.1(b)(5)). FDA may grant authorization for food use, rendering authorization solely for animal food use, or alternative disposition provided that the criteria in 21 CFR 511.1(b)(5) are met.").

235. As Van Eenennaam explained, because she cannot sell the beef, her laboratory must expend a substantial amount of grant money on animal disposal. Van Eenennaam Interview, *supra* note 152.

236. Van Eenennaam Interview, *supra* note 152.

do" that "it was just cheaper to burn them," which is exactly what she did."[237]

Second, Van Eenennaam and Oatley have both highlighted limited collaboration with commercial industry as another factor that constrains their research. Academics undertake projects related to GE food animals followed by seeking partnerships with industry players to advance their research.[238] This practice (commonly referred to as university spin-offs) is quite common in scientific research across various fields.[239] In certain biomedical areas, many scientific breakthroughs that reach the public domain originate from academic research and are subsequently adopted and refined by industry.[240] This process proves to be challenging in the GE food animal industry, and there is often a lack of motivation among potential industry partners to engage in such collaborations. Therefore, academics in the GE food animals field do not receive funding from industry, which is a common source of support for academic research.[241] Moreover, Oatley emphasized that this lack of collaboration undermines the utility of their research. Academics often have numerous ideas and projects they wish to pursue, many of which target traits that they believe will benefit the environment and human populations. The absence of collaboration with industry limits their ability to translate these ideas into practical applications or products that address industry needs. As Oatley explained:

> There [are] different lenses that people look through in academic science versus commercial development . . . . Academic science is about biological proof of concept. They want to show that it works . . . . The commercial world is about taking

237. *Id.*

238. Jon Oatley is one of the few individuals in this small industry to exemplify this approach by spinning off a startup directly from academic research. Oatley Interview, *supra* note 172.

239. *See The Impact of University Spin-Offs in the Life Sciences*, BIOTECHGATE (June 21, 2023), https://www.biotechgate.com/the-impact-of-university-spin-offs-in-the-life-sciences/ [https://perma.cc/X3TU-AC2U].

240. *Id.*; *see also* Sue Fletcher, *The Importance of Collaboration Between Academia and the Biotech Industry*, THERMO FISHER SCI. (Sep. 20, 2023), https://www.thermofisher.com/blog/biotechnology/the-importance-of-collaboration-between-academia-and-the-biotech-industry/ [https://perma.cc/6646-23XT]. *See generally* Qing Ke, *An Analysis of the Evolution of Science-Technology Linkage in Biomedicine*, 14 J. INFORMETRICS 101074, 101074 (2020) (finding a linkage of public science to private sector inventions).

241. *See* National Science Board, *Business Funding for University Research Grew Faster than Federal Funding in 2021*, NAT'L SCI. FOUND. (Oct. 5, 2023), https://www.nsf.gov/nsb/updates/business-funding-university-research-grew-faster-federal [https://perma.cc/TU3B-V3AW] (illustrating how businesses generally spend billions of dollars for research in academia).

> those discoveries and then getting them into a channel that money can be made out of, which does not always align with doing things for the good of populations. [Therefore,] one of the biggest challenges in getting biological proof of concept out of a lab into the public domain is a disconnect between the academic and commercial interface . . . . And in-between that sits the regulatory agencies like the FDA, [whose] . . . guidance and policies are not aligned well with the current state of science. [This poses challenges because those guidance and] policies tend to be behind . . . the pace of the science.[242]

* * * * *

The FDA has a clear objective driving its regulatory process: to ensure the safety of food and GE animals.[243] The FDA believes the current regulatory process strikes a balance between risks and benefits.[244] After engaging with stakeholders, however, it becomes apparent that the regulatory stage is at least *perceived* as a significant hurdle. Furthermore, the regulatory barriers are often prohibitive to developers even before they encounter other challenges. The burdensome nature of regulation makes it difficult for individuals to engage in genetic engineering projects, regardless of other obstacles they may face.[245] These effects matter. They harm the industry and result in significant lost benefits. The consequences extend to the economy,[246] the environment,[247] and even to animal welfare.[248] These costs stem from how FDA jurisdiction is defined and exercised, and they raise questions about statutory interpretation and the proper scope and exercise of federal regulatory authority over agricultural biotechnology.

---

242. Oatley Interview, *supra* note 172.

243. Solomon, *supra* note 160, at 142.

244. *Id.* at 143 ("We recognize that there is tremendous excitement over quickly embracing and bringing to market the fruits of genome-editing technology, as well as the critical importance of adequately identifying potential risks, efficiently evaluating whether the risks do in fact exist, and determining whether the risks pose an actual safety hazard in a timely manner. It is the FDA's role to balance these competing imperatives.").

245. *See generally* Aghion et al., *supra* note 219 (demonstrating that regulation can be considered a tax that makes it harder for innovation to thrive).

246. *See generally* Zilberman & Kaplan, *supra* note 144 (illustrating how every year of delay causes the loss of millions of dollars to the economy).

247. *See id.* at 2, 4 (offering examples of less harm and increased efficiency through adopting genetic engineering in farming practices).

248. Some examples include the hornless cattle that are bred to eliminate the need for dehorning and the PRRS-resistant pigs that are engineered to prevent infection with the porcine reproductive and respiratory syndrome virus. *See* NATURE BIOTECH., *supra* note 11.

IV. THE "DRUG INTERPRETATION" OF GENOMIC ALTERATIONS

The FDA treats IGAs in GE food animals as "drugs". Under the FDCA "[t]he term "drug" means . . . (C) articles (other than food) intended to affect the structure or any function of the body of man or other animals." The FDA treats the IGA within the animal as the relevant "article" that is being regulated.[249] Accordingly, even though the ultimate product is food, the FDA regulates IGAs in food animals as new animal drugs. This interpretation is not merely a technical regulatory classification — it is a statutory interpretation with major consequences for the structure, cost, and future of agricultural biotechnology.

As discussed in the preceding Sections, this interpretation and the regulatory requirements it entails create significant obstacles for developers and may limit society's ability to realize the benefits of this technology in the name of risk minimization. It does not reflect a balanced approach that adequately accounts for both the potential risks and the substantial benefits of GE food animals. The FDA continues to justify this interpretation on the view that it is necessary to ensure appropriate regulation of the technology. Meaningful shifts in this framework, at least from the FDA's standpoint, are unlikely in the near term, particularly following the finalization of its guidance in 2025.

The judicial branch also has limited capacity to address these issues, and courts are unlikely to provide an effective avenue for reform. This is so for several reasons. First, assessing the broader consequences of interpreting IGAs as "drugs" is not easily accomplished within the constraints of judicial proceedings. This limitation is illustrated by *Institute for Fisheries Resources v. Hahn*,[250] a 2019 decision reviewing the FDA's approval of AquaBounty's GE salmon. In that case, the Institute for Fisheries Resources and other organizations challenged the FDA's authority, arguing that genomic alterations should not be treated as "drugs" under the FDCA and that the agency therefore lacked jurisdiction.[251] Although the court acknowledged the potential consequences of denying FDA authority — particularly the risk of a regulatory vacuum — its analysis remained narrowly focused on that concern.[252] The court did not meaningfully consider alternative regulatory frameworks that might allow for oversight without relying on the FDCA's drug provisions, nor did it engage with the potential costs and innovation-limiting effects of maintaining the FDA's current approach. This suggests that courts, operating within the confines of specific disputes, are not well

249. GUIDANCE 187B, *supra* note 18, at 3.
250. 424 F. Supp. 3d 740 (N.D. Cal. 2019).
251. *Id.* at 751–52.
252. *Id.* at 744.

positioned to evaluate the broader policy implications of the FDA's interpretive choices.

Second, courts may be reluctant to assert jurisdiction over the FDA's interpretation of the FDCA's drug provisions. In *Institute for Fisheries Resources*, for example, the court expressed reservations about whether the FDA's guidance constituted a final agency action subject to judicial review under the Administrative Procedure Act.[253] This hesitation underscores the procedural barriers to judicial review and further limits the courts' ability to meaningfully engage with the substance of the FDA's interpretive choices. Courts may decline to review the FDA's guidance on the ground that it is merely a nonbinding document containing "recommendations" and lacking "direct and appreciable legal consequences" for the plaintiffs. These concerns were evident in *Institute for Fisheries Resources* and may arise in future cases as well. Although some of these procedural barriers might be overcome if plaintiffs directly affected by the FDA's interpretation — such as developers subject to the regulatory framework — were to bring suit, such legal challenges are unlikely to be brought in practice. Those most directly affected by the FDA's approach are developers and researchers in biotechnology, many of whom may lack the resources to pursue complex litigation. Moreover, these actors may be reluctant to challenge the FDA given their dependence on the agency for product approvals. Larger companies, which are more capable of sustaining such litigation, may likewise have limited incentives to do so. The current regulatory framework may benefit established firms by increasing compliance costs and thereby raising barriers to entry, reducing competition from smaller innovators. Taken together, these factors suggest that judicial review of the FDA's interpretation is unlikely to occur, whether due to procedural obstacles, limited incentives, or strategic considerations among affected parties.

Third, even if these obstacles were overcome with suitable plaintiffs bringing a challenge and a court agreeing to review the FDA's interpretation, the outcome of such review is unlikely to produce meaningful change. A court might ultimately uphold the FDA's interpretation as a permissible reading of the statute or adopt an alternative interpretation that does not significantly alleviate the regulatory burdens identified above or better accommodate innovation. In fact, the FDA's position may be increasingly vulnerable to judicial scrutiny in the wake of *Loper Bright Enterprises v. Raimondo*.[254] *Loper Bright* altered the balance of judicial intervention in agency statutory

253. *Id.* at 747.
254. 603 U.S. 369 (2024).

interpretation.[255] Rejecting *Chevron*'s more deferential approach,[256] *Loper Bright* held that courts may no longer defer to reasonable agency interpretations when a statute is ambiguous; instead, courts must exercise independent judgment to determine the best interpretation of the statute.[257] This change is particularly significant for highly technical regulatory fields like biotechnology, where courts lack the scientific and technical expertise that agencies like the FDA possess.[258] And despite this change, the complexity of the subject matter and the need to grapple with the broader regulatory consequences make it unlikely that judicial intervention will yield a more effective or coherent framework. Accordingly, even under a post-*Loper Bright* administrative law landscape, judicial review does not offer a reliable path toward reform.

At the same time, this doctrinal shift exposes the current regulatory framework for GE animals to increased legal uncertainty. If a future court were to conclude that the FDCA's definition of "drug" does not encompass genetic traits within animals, the FDA's jurisdictional basis could be significantly undermined. Whether such a reinterpretation would be beneficial or not, this instability itself carries costs. It may exacerbate existing uncertainty, discourage investment, and delay innovation, as developers and investors adopt a wait-and-see approach pending potential changes in the regulatory landscape.

---

255. Nowell D. Bamberger, Carmine D. Boccuzzi, Jr. & William Baldwin, *After Chevron: What the Supreme Court's Loper Bright Decision Changed, and What It Didn't*, HARV. L. SCH. F. ON CORP. GOVERNANCE (July 18, 2024), https://corpgov.law.harvard.edu/2024/07/18/after-chevron-what-the-supreme-courts-loper-bright-decision-changed-and-what-it-didnt/ [https://perma.cc/SV6K-5B3H] ("Overturning the longstanding doctrine known as '*Chevron* deference,' *Loper Bright* expands the judiciary's power to review and reject interpretations of statutes adopted by federal administrative agencies."); *see also* Thomas W. Merrill, *The Demise of Deference — and the Rise of Delegation To Interpret?*, 138 HARV. L. REV. 227, 228–29 (2024) ("*Loper Bright* mandates a one-step approach in which the court always has the last word, but that includes an augmented conception of the traditional tools of interpretation designed to allow the court to take advantage of agency expertise and insights, and to enforce congressional signals about the appropriate interpreter in particular circumstances.").

256. Under the former Chevron "two-step" framework, courts would first ask whether Congress has clearly addressed the ambiguity in question using traditional statutory interpretation. If so, that answer controls and the court ends its inquiry. If not, the court defers to any reasonable agency interpretation of the statute, even where the agency's reading was not what the court regarded as the best interpretation. Chevron U.S.A. Inc. v. Nat. Res. Def. Council, Inc., 467 U.S. 837, 842–43 (1984); *see* Merrill, *supra* note 255.

257. *See* 603 U.S. at 412–13.

258. *See* Sapna Kumar, *Scientific and Technical Expertise After Loper Bright*, 74 DUKE L.J. 1749, 1754 (2025) ("Considering the impact of other recent Court decisions regarding administrative law, agencies are now under significant control by generalist judges who neither possess scientific backgrounds nor have access to relevant experts. The best-case scenario is that judges will either surreptitiously defer to agencies or take longer to decide cases as they attempt to educate themselves. The worst-case scenario is that judges will make major errors regarding science and technology . . . .").

This underscores the need for a clearer legislative solution. Rather than asking courts to stretch 1938 laws to cover twenty-first century biotechnology, we should have a tailored regulatory framework that provides both legal certainty and efficiency in regulating biotechnology. Yet, until such change occurs, we are left with the FDA's current approach, along with its difficulties. The next Section offers four possible readings of the statutory term "article"[259] and demonstrates why they are not well suited for GE animals.

A. The Regulated Object: The "Article"

An important component of the definition of the term "drug" in the FDCA is the "article" being classified as the drug. One of the definitions of the term "drug," which the FDA relies on, is "articles (other than food) intended to affect the structure or any function of the body of man or other animals."). But what exactly is the "article" being regulated in the case of GE food animals? This Article offers four possible candidates: (1) the DNA construct that is injected into an embryo to alter its genome; (2) the embryo into which the construct is introduced before implantation in the host animal; (3) the altered DNA *within* the animal — the interpretation FDA has adopted;[260] and (4) the GE animal itself.

The FDA's interpretation, under which the altered DNA inside the GE animal is the "article" and therefore a "drug" under the FDCA, is not entirely convincing. While DNA is ordinarily an intrinsic component of the organism, the FDA treats IGAs in animals as the regulated "article," even though that "article" is part of the animal's genome rather than an external substance administered to the organism's body. Courts generally treat external agents as "articles," such as chemicals that are applied to the body to cause modifications. This is supported by legal cases where the definition of a "drug" was contested.[261] One of the most prominent cases addressing the definition of "drug" involved the FDA's jurisdiction to regulate tobacco.[262] Although the Court did not explicitly address the distinction between

259. 21 U.S.C. § 321(g)(1).

260. GUIDANCE 187B, *supra* note 18, at 2.

261. *See, e.g.*, United States v. Article Consisting of 216 Cartoned Bottles, More or Less, Sudden Change, 409 F.2d 734, 736–37 (2d Cir. 1969) (finding that a cosmetic lotion applied externally on the skin was a "drug" under the FDCA because its promotional claims indicated it was intended to affect the structure of the skin); United States v. Bacto-Unidisk, 394 U.S. 784, 787 (1969) (holding that antibiotic sensitivity test discs were "drugs" under the FDCA because they externally introduce a component that modifies the body).

262. FDA v. Brown & Williamson Tobacco Corp., 529 U.S. 120 (2000). In this case the Court did not seriously dispute that nicotine may fall within the broad statutory definition of a drug because of its effects on the body and its intended use. Nevertheless, the Court held that the FDA lacked jurisdiction to regulate tobacco products under the FDCA, reasoning that Congress had clearly established a distinct regulatory framework for tobacco.

internal and external substances in this case, its analysis reflects an implicit recognition that the concept of a "drug" typically involves substances introduced into an *existing* body to affect its structure or function.[263] This understanding also follows from a natural reading of the statutory text, which defines drugs as "articles" intended to affect the structure or any function of the *body* of man or other animals — language that suggests discrete items acting upon the body.[264]

This interpretive difficulty highlights the challenges of applying existing legislation to new technologies. Genetic modification technology blurs the lines traditionally drawn in drug regulation. Typically, the process of drug regulation involves two stages: the development and manufacture of the drug, followed by its administration to an animal.[265] In the case of genetic alterations, however, these stages collapse into one. The creation of the "drug" — that is, the genetic alteration itself, if one accepts the FDA's interpretation — and its "administration" happen simultaneously. There are no external articles being produced and then administered to the animal. Instead, the genetic alteration is coexistent with the animal. Therefore, it is hard to say that altered DNA within the animal is considered an "article" that modifies the animal's body: since it *is* the body, it *is* the animal.

It is also difficult to identify caselaw addressing this particular issue, in part because courts usually confront situations in which external components of the body are treated as "drugs."[266] This may reflect the fact that such claims are not easily supported by the statutory text, and therefore have seldom been litigated. A related line of cases arises in the context of stem cell therapies. In *United States v. Regenerative Sciences, LLC*,[267] the defendant extracted a sample of a patient's bone marrow or synovial fluid and isolated mesenchymal stem

263. *Id.* at 126 (describing nicotine as a pharmacologically active substance delivered to the body through the consumption of tobacco products).

264. *Id.*

265. *See, e.g.*, HASSAN Z. SHEIKH, CONG. RSCH. SERV., R41983, HOW FDA APPROVES DRUGS AND REGULATES THEIR SAFETY AND EFFECTIVENESS, SUMMARY (May 8, 2018), https://sgp.fas.org/crs/misc/R41983.pdf [https://perma.cc/5XFV-ED5B] (Aug. 8, 2018) ("In the preapproval (premarket) phase, FDA reviews manufacturers' applications to market drugs in the United States; a drug may not be sold unless it has FDA approval. Once a drug is on the market, FDA continues its oversight of drug safety and effectiveness. That postapproval (postmarket) phase lasts as long as the drug is on the market.").

266. Central cases interpreting the definition of "drug" under the FDCA involve external substances introduced into the body, rather than internal biological components, like DNA. *See supra* notes 261–264 and accompanying text. Additional caselaw confirms this pattern, as courts addressing the statutory definition have done so in the context of products that are distinct from, and act upon, the body. *See infra* notes 267–269 and accompanying text. One notable exception is Inst. for Fisheries Res. v. Hahn. 424 F. Supp. 3d 740 (N.D. Cal. 2019). In this case, the court considered whether intentionally altered DNA, an internal component of the body, could be regulated as a drug, and ultimately accepted the FDA's position that it falls within the statutory definition.

267. 741 F.3d 1314 (D.C. Cir. 2014).

cells, which are capable of differentiating into bone and cartilage cells. These cells were then cultured — caused to divide and proliferate — and, once there was enough, reinjected into the same patient at the site of injury.[268] The court held that the resulting mixture injected into the patient qualified as a "drug," noting that the statutory definition "clearly appl[ies] to the Mixture, an article derived mainly from human tissue and intended to treat orthopedic diseases and to affect musculoskeletal function."[269] Importantly, although the primary component of the "drug" consisted of the patient's own cells, the court treated the product as a drug because the cells had been extracted, manipulated, and reintroduced into the body. In other words, once removed from the body and processed, the cells were no longer treated as part of the organism itself, but as a distinct article administered to it. This situation differs significantly from GE animals and IGAs. In those contexts, there is no extraction and reintroduction of cells or DNA. Instead, genetic changes are introduced at the cellular stage, and the organism develops with those changes already incorporated into its genome. The DNA is never external to the organism in the way contemplated in *Regenerative Sciences*; rather, it is constitutive of the organism from the outset at the cell level.

This interpretation of IGAs as "drugs" also creates inconsistencies in the regulatory system, which in turn raises concerns about the soundness of this interpretation. A useful analogy arises in the context of animal cloning: The FDA's treatment of animal cloning highlights a potential inconsistency in its interpretation of the FDCA. Cloning involves taking the nucleus (and thus the DNA) from a somatic cell of an existing animal and inserting it into an enucleated egg cell, which then develops into an organism genetically identical to the donor animal.[270] Initially, it was unclear whether such cloning practices should be regulated under the FDCA as a "drug."[271] The FDA declined to resolve this question definitively and instead exercised enforcement discretion, choosing not to regulate animal cloning — whether for food or non-food purposes — under the new animal drug provisions.[272]

---

268. *Id.* at 1318.

269. *Id.* at 1319.

270. U.S. FOOD & DRUG ADMIN., ANIMAL CLONING: A RISK ASSESSMENT 3 (2008).

271. NAT'L RSCH. COUNCIL, ANIMAL BIOTECHNOLOGY: SCIENCE-BASED CONCERNS 162 (2002) ("It is unclear whether any agency has jurisdiction to make market access decisions or establish conditions of use for cloned animals.").

272. U.S. FOOD & DRUG ADMIN., GUIDANCE FOR INDUSTRY #179: USE OF ANIMAL CLONES AND CLONE PROGENY FOR HUMAN FOOD AND ANIMAL FEED 3 (2008) [hereinafter GUIDANCE 179] ("Assuming, without here deciding, that any part of SCNT or animal clones, based on being derived from SCNT, meet the statutory definition of new animal drug under the [FDCA], at this time, FDA does not intend to regulate any such new animal drugs. This intent not to regulate (i.e., the intent to exercise enforcement discretion) applies to both non-food and food-producing species.").

Cloning shares important structural similarities with GE animals. In both cases, modifications occur at the cellular level, and those modified cells give rise to a complete organism. While cloning does not introduce novel DNA but instead replicates the genome of an existing organism, it nevertheless involves a profound alteration of the recipient egg cell, whose entire genome is replaced with that of another animal. This comparison raises a potential inconsistency. The FDA treats IGAs as "drugs," yet cloning — despite involving a complete replacement of the egg's genome — is not treated in the same way. One possible explanation for this difference is that IGAs introduce changes to an organism's genome, whereas cloning merely copies an existing genome without altering it. But this distinction depends on the baseline used for comparison. If one compares the cloned animal to the donor animal, then indeed there is no genomic change. However, that comparison is difficult to reconcile with the statutory definition of a drug, which focuses on whether an "article" is intended to affect the structure or function of the body of the organism in question. From that perspective, the relevant comparison is not between two already-existing animals, but between the organism that would have developed from the original egg cell and the organism that develops following the nuclear transfer. On that view, cloning involves a complete transformation of the developing organism's genome — arguably a more radical change than many IGAs. Comparing the organism that would have developed absent intervention with the resulting cloned animal highlights this distinction. Whereas IGAs typically modify specific, identifiable genes, cloning replaces the entire genome. Therefore, if cloning does not involve an "article" introduced into the body, despite the complete replacement of the organism's genome, it is unclear why specific genomic alterations should be treated differently. This inconsistency raises questions about the coherence of the FDA's interpretation and its strength.

Another important example of the difficulties stemming from the FDA's interpretation is the inconsistent regulatory treatment of GE plants and animals. While a single nucleotide alteration in a plant may be exempt from biotechnology regulation by the FDA and the USDA, the same change in an animal is subject to drug regulation.[273] The FDA justifies this distinction by pointing to differences in statutory frameworks, risk profiles, and potential harms associated with animals as compared to plants.[274] It is true that animals and plants differ in important ways. Animals often involve more complex biological

273. Hallerman et al., *supra* note 41, at 188.

274. *See* Laura Epstein, *FDA Regulation of Animals with Intentionally Altered Genomic DNA*, Powerpoint Presentation at the USDA ARS 5th International Biosafety & Biocontainment Symposium (Feb. 2019), https://arssymposium.org/wp-content/uploads/2019/02/445-SIIIMS-Epstein.pdf [https://perma.cc/3VT9-Y6K7].

systems, and concerns regarding animal welfare are significantly more salient in the context of food animals than in plants. These differences may justify some divergence in how research and production are regulated. However, they do not necessarily justify subjecting all GE food animals to the full new animal drug approval process. Many plant species naturally synthesize anti-nutritional or toxic compounds as a defense against herbivory, whereas food-animal species do not typically express such toxins. [275] Moreover, there is no evidence that GE animals have introduced novel food allergens or food intolerances, whereas such concerns have been identified in certain genetically engineered crops.[276] As a result, the risk that GE food animals would introduce comparable hazards, particularly toxicity and novel food allergens, is relatively limited. Moreover, while the FDA is correct to emphasize animal welfare — a concern largely absent from plant biotechnology — the new animal drug approval framework is an imperfect tool for addressing that objective. Much of the approval process focuses on issues such as durability, food composition, and the characterization of genomic changes, rather than the ethical or physiological well-being of the animal. Accordingly, although the distinct characteristics of animals may warrant some form of differentiated oversight, they do not justify the application of the drug approval regime. Instead, this inconsistency in regulatory treatment appears to stem primarily from statutory differences rather than risk-based considerations, as IGAs in animals fall within the definition of "animal drugs" while IGAs in plants do not.

Several alternative interpretations of "article" are possible, though each presents conceptual and legal difficulties. First, could the DNA construct (before being injected into the cell) that is used to alter the genome be considered the regulated "article"? This interpretation arguably makes more sense than treating the altered DNA *within* the animal as the "article." The DNA construct is a tangible, external item introduced into a biological system. However, this construct is not introduced into a fully developed animal. Genomic modifications typically occur at a very early developmental stage.[277] The process often involves embryonic or pluripotent cells.[278] But the language of

275. NAT'L ACADS. OF SCIS., ENG'G, & MED., *supra* note 61, at 62.

276 *Id.* at 61.

277. *See* Elena Rice, *Taking PRRS Virus Resistant Pigs Through Regulatory Approvals*, Powerpoint Presentation at the 5th International Workshop on Regulatory Approaches for Agricultural Applications of Animal Biotechnologies, ISAAA (Aug. 19–22, 26–29, 2024), https://www.isaaa.org/kc/proceedings/animalbiotechnology/2024-5th-intl-workshop/session02/pdf/Taking%20PRRSVresistant%20pigs%20through%20the%20regulatory%20process%20-%20Elena%20Rice%2C%20Genus%20plc.pdf [https://perma.cc/3TUP-SKM9] (illustrating one example of gene editing where modifications are introduced at the pre-embryo stage of development).

278. *Id.*

the statutory definition does not encompass genetic alterations of cells destined to become animals in the future. The statutory text more naturally suggests that the regulation applies to effects on the body as a whole, not merely on cells outside the body.[279]

Extending the scope to cellular effects alone would mean that any cell-based research could be deemed "drug" research — an interpretation that would be excessively broad. If any article intended to affect the structure of a cell were classified as a drug, then the vast array of reagents and tools used for in vitro research would theoretically fall under the FDCA's "drug" category simply because they alter cellular function. This interpretation would subject biological research tools to the same onerous premarket approval requirements designed for commercial pharmaceuticals, effectively paralyzing scientific inquiry by regulating the research *process* as if it were a finished medical *product*. However, a possible distinction may be drawn between genetic constructs used as research tools and those intended to produce GE animals. Where the construct is used solely for cellular-level research, it may fall outside the statutory definition of a drug, which turns on intended use.[280] By contrast, where the construct is intended to produce an animal carrying the altered DNA, treating it as the regulated "article" may be more defensible and avoids the broader implications of this interpretation for biological research. In practice, however, this distinction may be difficult to maintain, particularly where the research itself includes the development of animals, not only cells, with genetic changes.

Another possible interpretation is that the embryo — containing the altered genome and transferred into a host animal — constitutes the "article." To treat an embryo as an "article" intended to alter the structure of the host animal stretches the statutory language beyond reasonable limits. If this interpretation were adopted, the regulatory consequences would be sweeping: any in vitro fertilization procedure, or even standard artificial insemination, could theoretically be classified as the administration of a "new animal drug" because it introduces an external entity intended to change the host's physiological state (pregnancy). Such a reading is inconsistent with the FDA's practice. The FDA's own guidance distinguishes IGAs produced through modern molecular technologies from "selective

279. *See* Richard A. Merrill & Bryan J. Rose, *FDA Regulation of Human Cloning: Usurpation or Statesmanship?*, 15 HARV. J.L. & TECH. 86, 123 (2001); *see also supra* notes 267–269 and accompanying text.

280. *See infra* notes 284–90 and accompanying text for further discussion of the intentional component in the "drug" statutory definition.

breeding or other assisted reproductive technologies."[281] In the cloning context, the FDA did not determine whether cloning should be regulated as a "drug." Instead, the agency exercised enforcement discretion without definitively addressing the cloning's legal classification, even though the process involves the transfer of an embryo into a host organism.[282] Legal scholars have rejected this interpretation in the context of human cloning, arguing that an embryo cannot reasonably be defined as an "article" under the FDCA.[283]

A final possibility is that the genetically modified animal itself is the "article" being regulated by the FDCA. The FDA has rejected this view.[284] Beyond the semantic awkwardness of labeling a living animal a "drug" or "article," the modified animal is not intended to alter the structure or function of other animals or humans. Courts have emphasized the importance of the intended use of a product in determining whether that product falls under the FDCA's statutory "drug" classification.[285] Intent can be determined by a combination of factors, e.g., what the developer claims their product is for and how the product is marketed, distributed, and used.[286] Although the FDA characterizes IGAs as intended to affect the structure or function of the animal's body, the relevant article under this alternative framing would be the animal itself. And the animal, as introduced into commerce, is

---

281. *See* GUIDANCE 187A, *supra* note 17, at 1, n.5 ("The term 'modern molecular technologies' does not include induction of polyploidy by heat, pressure, or chemical treatment or selective breeding or other assisted reproductive technologies. These methods are outside the scope of this guidance document.").

282. *See* GUIDANCE 179, *supra* note 272.

283. Elizabeth C. Price, *Does the FDA Have Authority To Regulate Human Cloning?*, 11 HARV. J.L. & TECH. 619, 630 (1998) ("It is highly unlikely, however, that a court would find that an embryo could properly be considered an 'article' within the meaning of the FDCA. If it were, all human embryos would be subject to prior approval and/or licensure by the FDA, whether created by passion or the petri dish. Thus, if a court were to conclude that an embryo is an 'article' under the FDCA, it would, by necessary implication, give the FDA authority to pre-approve the formation of all human life. Such an absurd construction of the term 'article' is in keeping neither with common sense nor legislative intent."); Merrill & Rose, *supra* note 279, at 124 ("Suffice it to say, the FDCA's 'drug' definition does not comfortably encompass all of the applications now awaiting investigation. In particular, it is an awkward fit for procedures whose objective is to produce new human beings.").

284. GUIDANCE 187B, *supra* note 18, at 2–3.

285. *See, e.g.*, Nat'l Nutritional Foods Ass'n v. Mathews, 557 F.2d 325, 333, 335 (1977) (ruling against the FDA because the agency lacked sufficient evidence that the sellers intended the product for therapeutic use); United States v. Travia, 180 F. Supp. 2d 115, 118 (D.D.C. 2001) ("The intended use of an article thus determines whether it is classified as a 'drug' for purposes of the FDCA."). The federal regulatory provision issued by the FDA also discusses the "intended use" of an article. 21 C.F.R. § 201.128 (2025).

286. 21 C.F.R. § 201.128 (2025) ("The intent may be shown by such persons' expressions, the design or composition of the article, or by the circumstances surrounding the distribution of the article. This objective intent may, for example, be shown by labeling claims, advertising matter, or oral or written statements by such persons or their representatives. Objective intent may be shown, for example, by circumstances in which the article is, with the knowledge of such persons or their representatives, offered or used for a purpose for which it is neither labeled nor advertised.").

intended for human consumption as food — not for use in affecting the structure or function of the human body. Accordingly, if the regulated "article" were the animal rather than the IGA within it, the product would more naturally fall within the statutory category of food rather than drugs.

A useful parallel for determining whether the relevant "article" is the IGA or the animal can be found in biopharmaceuticals, particularly in edible vaccine crops (i.e., biopharming).[287] Biopharmaceutical technologies use genetic engineering to transform food into drugs. For example, an apple genetically engineered to contain vaccine components begins as food but is engineered to function as a drug.[288] In that case, the product is regulated as a biologic, despite being a modified food item, because of its intended use.[289] If biopharmaceutical food products are classified as drugs because their genetic modification serves a pharmaceutical function, should not GE food animals be classified as food because their genetic modification serves an agricultural function? The FDA has treated biopharmaceuticals as drugs if the ultimate purpose of their genetic modification is therapeutic.[290] Applying that same reasoning here, the ultimate purpose of GE food animal modifications is food production, not pharmaceutical use. By maintaining the drug paradigm for GE animals, the FDA is applying inconsistent logic, one that selectively emphasizes intent when it serves to expand regulatory jurisdiction but disregards it when it does not.

In sum, none of the four potential interpretations resolve the issue in a fully satisfactory way. To develop a more complete account beyond the textual analysis, the next section turns to an examination of the statute's legislative purpose.

---

287 . *See* Jyoti Saxena & Shweta Rawat, *Edible Vaccines*, in ADVANCES IN BIOTECHNOLOGY 207, 208 (Indu Ravi et al. eds., 2014); Birdsall, *supra* note 86, at 274.

288. *See* Saxena & Rawat, *supra* note 287, at 208–10 (discussing transgenic potatoes engineered with a cholera antigen to aid immunization as an example of edible vaccines that "introduce[e] selected desired genes into plants and then induc[e] these altered plants to manufacture the encoded proteins").

289. Birdsall, *supra* note 86, at 283 ("[For edible food vaccines], the manufacturer intent would guide the classification. If the manufacturer truly intended a new bioengineered product to primarily be a food, then it would be regulated as one. The same would apply to a manufacturer's intent to regulate a product as a drug.").

290. *See* U.S. DEP'T OF AGRIC., U.S. ENV'T PROT. AGENCY & U.S. FOOD & DRUG ADMIN., THE COORDINATED FRAMEWORK FOR THE REGULATION OF BIOTECHNOLOGY: PLAIN LANGUAGE INFORMATION ON THE BIOTECHNOLOGY REGULATORY SYSTEM 14 (2023) ("CVM regulates animal drugs and medical devices for animals, including any made from modified plants . . . .").

B. Legislative Purpose

The question whether a GE food animal should be regulated as a "drug" hinges on a statutory definition that has remained substantially unchanged since the enactment of the FDCA in 1938.[291] This raises the question of how this language can cover genetic engineering that did not exist at the time of its drafting and could not have been anticipated by the lawmakers of that era.[292] Given that the 1938 Congress could not have anticipated this technology, the text of the FDCA offers limited guidance on its application to modern genetic engineering. It is necessary to look beyond the text to the broader legislative purpose underlying the FDCA to determine if the FDA's interpretation aligns with the original intent of the Act.

The statutory background and drafting history of the FDCA reveal that Congress intended to establish a broad definition of the term "drug" and an expansive regulatory framework for the FDCA. Before the enactment of the FDCA in 1938, the Pure Food and Drugs Act defined "drug" to encompass "all medicines and preparations recognized in the United States Pharmacopoeia or National Formulary for internal or external use," as well as "any substance or mixture of substances intended to be used for the cure, mitigation, or prevention of disease of either man or other animals."[293] Congress broadened the definition of "drug" to the current definition in the FDCA. According to certain representatives in Congress, the amendment was necessary because the existing law was deemed to have "serious loopholes" and was "not sufficiently broad in its scope to meet the requirements of consumer protection under modern conditions."[294] Part of the trigger behind expanding the definition under the FDCA stemmed from concerns regarding dangerous and ineffective weight-loss products that had evaded regulation under the previous definition of the term "drug."[295] It appears that Congress recognized the FDCA's potential to extend beyond weight-loss products and encompass other items intended to impact the structure or function of the body.[296]The drafting history

---

291. *Compare* Federal Food, Drug, and Cosmetic Act, Pub. L. No. 75-717, § 201(g), 52 Stat. 1040, 1041 (1938), *with* 21 U.S.C. § 321(g)(1) (showing that the only meaning change is the removal of a trailing clause excluding devices, which is irrelevant to this Article's discussion).

292. The technology of GE animals emerged only in the 1980s, and genetic engineering started in the 1970s in general. *See generally* Brinster et al., *supra* note 45, at 223.

293. Pure Food and Drugs Act of 1906, ch. 3915, § 6, 34 Stat. 768, 769.

294. H.R. REP. NO. 75-2139, at 1 (1938).

295. S. REP. NO. 74-361, pt. 1, at 3 (1935).

296. H.R. REP. NO. 75-2139, at 2 ("Drugs intended for diagnosing illness or for remedying underweight or overweight or for otherwise affecting bodily structure or function are subjected to regulation.").

offers further evidence suggesting that Congress intended for the definition of the term "drug" to have a broad scope.[297]

It is uncertain, though, whether this intent and the FDCA's language are sufficiently comprehensive to encompass the relatively novel case of genomic alterations. Genomic alteration technology is markedly distinct from what was known during the congressional hearings in 1938, which occurred several years before the importance of DNA to inheritance was known.[298] While Congress may have opted for broad language to accommodate future technologies, it is likely that the language still falls short in this particular instance.

In fact, the statutory distinction between a "device" and a "drug" offers insight into the intent and purpose behind the provision. Early drafts of the FDCA had included within the definition of "drug" not only chemical substances, but also "devices intended to affect the structure or function of the body" within the definition of "drug."[299] During congressional hearings, a member of Congress asked Walter Campbell, the head of the FDA in 1938, whether this definition would extend to "ultraviolet lights and various instruments of that sort."[300] Campbell responded that it would, because the portion of the "drug" definition that encompassed "devices" was "admittedly an inclusive, wide definition."[301] The agency further explained that the definition would also reach items such as therapeutic belts, emphasizing that the statutory language was deliberately "inclusive." These remarks, however, prompted concern among members of Congress that the device-related portion of the proposed "drug" definition was so expansive that it could sweep in a wide range of trivial or commonplace products.[302] They did not object to the regulation of those products under the FDCA, but instead to the characterization of such products as "drugs."[303] In response to these concerns, the bill was revised to exclude devices from the statutory definition of "drug" and to establish a distinct definition of "device," modeled on and closely paralleling the FDCA's revised definition of "drug."[304]

The separation between "drugs" and "devices" suggests that Congress sought to exclude cases that deviate significantly from the common understanding of a "drug." Legally, there is no barrier to

297. *See id.* at 3.

298. *See generally* Oswald T. Avery, Colin M. MacLeod & Maclyn McCarty, *Studies on the Chemical Nature of the Substance Inducing Transformation of Pneumococcal Types: Induction of Transformation by a Desoxyribonucleic Acid Fraction Isolated from Pneumococcus Type III*, 79 J. EXP. MED. 137 (1944) (identifying DNA as the "transforming principle" responsible for transferring genetic information).

299. S. Rep. No. 73-493, at 2 (1934).

300. CHARLES WESLEY DUNN, FEDERAL FOOD, DRUG, AND COSMETIC ACT 1053 (1938).

301. *Id.*

302. *See id.* at 286–92; United States v. Bacto-Unidisk, 394 U.S. 784, 795–96.

303. *See* DUNN, *supra* note 300, at 286–92.

304. *See id.* at 1247; Bacto-Unidisk, at 796–97.

classifying devices as "drugs," as legislators are not bound by dictionary definitions.[305] Congress's deliberate decision to differentiate the two suggests that Congress did not intend to classify "things" as "drugs" when they fall too far outside the conventional notion of a drug. This implies that while Congress intended a broad definition of the term "drug," Congress may not have intended it to extend so far as to encompass entirely distinct cases, like genetic alterations.

Current and former officials from the FDA and the USDA have provided insight into the historical context and mindset within the FDA at the time the decision was made to classify altered DNA of animals as animal "drugs." Larisa Rudenko, a former FDA official who wrote and worked on the formulation of the FDA's regulations, stated that the regulations were developed when "there was a huge movement against genetic engineered anything . . . [with] a lot of opposition . . . [that] was sort of ethical."[306] She shared that this resulted in a "conflation of ethics and safety" because the FDA did not have a clear "vehicle or venue . . . [to] take public opinion [about ethical or moral concerns] into account" when formulating those regulations.[307]

Rudenko also highlighted another contextual factor. She pointed out that the regulatory decision came shortly after the emergence of animal cloning technology, when "some very early papers on animal cloning . . . reported that . . . some of the animals that came out of the cloning process were deformed."[308] While this was true, Rudenko emphasized the importance of noting that this was "very early in the technology before anybody understood really what was going on."[309] She believes that this historical context of "basic mistrust of the [GE] technology" played a role in the FDA's decision-making process regarding whether and how to regulate the technology.[310]

It is also significant to note that the FDA's regulatory focus on GE animals initially stemmed from their use in biopharmaceutical production, specifically in the development of drugs and biologics.[311]

---

305. *See* Inst. for Fisheries Res. v. Hahn, 424 F. Supp. 3d 740, 752 (N.D. Cal. 2019).

306. Interview with Larisa Rudenko, Former Senior Advisor for Biotechnology, U.S. Food & Drug Admin. (Mar. 14, 2024).

307. *Id.*

308. *Id.*

309. *Id.*

310. *Id.* While this historical background provides valuable insights into the FDA's approach to regulating GE animals, Rudenko emphasized that her perspective is personal and does not necessarily reflect the official stance of the FDA. *See id.* Nonetheless, as a key official involved in the regulation of GE animals at that time, Rudenko's viewpoint remains significant, even if it is not the same as the formal position of the FDA.

311. The first product to be examined and approved by the United States was GE goats intended to produce a protein that helps prevent blood clots for the treatment of humans in the early 2000s. New Animal Drugs: Bc6 Recombinant Deoxyribonucleic Acid Construct, 74 Fed. Reg. 6823, 6823 (Feb. 11, 2009); *see also Intentional Genomic Alterations (IGAs) in*

As Wray-Cahen observes, the FDA's interpretations and guidance can be illustrated through the FDA's examination of the ATryn goats.[312] These goats were genetically engineered to produce a human biologic protein, known as ATryn, in their milk.[313] The purpose of this protein was to prevent fatal blood clots in individuals with a rare condition. Therefore, because the FDA has focused its initial regulatory guidance and first approval on drug use, its guidance did not differentiate between products that sought approval for different uses, such as between drug use and food or agricultural use.[314] This rationale provided the basis for regulating GE animals under the "new animal drug" provisions of the FDCA. In the context of the ATryn goat and other biomedical applications, the drug classification was justified, as it aligned with the core purpose of the "drug paradigm" — ensuring the safety and efficacy of substances intended to diagnose, cure, mitigate, treat, or prevent diseases. But the technical landscape has since evolved. The use of GE animals has expanded beyond pharmaceutical applications to encompass agriculture and environmental sustainability.[315] This shift complicates the continued application of the same regulatory framework.

Moreover, while mistrust in biotechnology may have justified a highly precautionary approach in the past, this consideration does not necessarily remain valid today, given the greater scientific understanding, regulatory experience, and empirical data now available regarding GE animals.[316] In the past, regulating GE food animals under the FDCA's drug provisions may have been perceived as a precautionary necessity. Today, the regulatory and scientific environment is vastly different.

Given these developments, it is no longer evident that the FDCA's purpose aligns with an expansive interpretation that treats all GE animals, including GE food animals, as drugs. The FDA acknowledges that it must strike a balance between ensuring public safety and enabling technological advancement.[317] But the current regulatory treatment of GE food animals appears misaligned with this broader

---

Animals, U.S. FOOD & DRUG ADMIN., https://www.fda.gov/animal-veterinary/biotechnology-products-cvm-animals-and-animal-food/intentional-genomic-alterations-igas-animals [https://perma.cc/3KE4-TLKR].

312. Wray-Cahen Interview, *supra* note 178. *See generally Transgenic Drug Gets Green Light from the United States*, 457 NATURE 775 (2009) (announcing the FDA's approval of ATryn).

313. *See generally Transgenic Drug Gets Green Light from the United States, supra* note 312.

314. Wray-Cahen Interview, *supra* note 178.

315. *See generally* Wray-Cahen et al., *supra* note 6.

316. *See, e.g.*, Karinne Ludlow, Jose Falck-Zepeda & Stuart J. Smyth, *Risk-Appropriate, Science-Based Innovation Regulations Are Important*, 43 TRENDS BIOTECH. 502, 506 (2025).

317. Solomon, *supra* note 160, at 143 ("It is the FDA's role to balance these competing imperatives.").

purpose. Rather than achieving a measured balance between risk mitigation and innovation, the existing framework disproportionately burdens agricultural applications of genetic engineering, hindering its potential benefits. As such, the continued application of the "drug" classification in order to regulate GE food animals may extend beyond the intended scope of the law.

V. REGULATORY ALTERNATIVES

Overly stringent regulation can hinder innovation, while the absence of regulation can accelerate it.[318] This does not suggest that regulation is unnecessary, but that it must be carefully balanced against the potential societal benefits that emerging technologies may offer.

This Part surveys alternative regulatory approaches to GE food animals. It explains why classifying GE food animals as food, categorizing them as food additives, or relying on expanded enforcement discretion fail to provide a workable and predictable framework. It then argues that meaningful reform for the long term likely requires new legislation and concludes by drawing lessons from Argentina and Brazil, which have adopted more innovation-friendly regulatory models for GE animals.

A. Food

Under section 321(f) of the FDCA, the term "food" is broadly defined as:

> (1) articles used for food or drink for man or other animals, (2) chewing gum, and (3) articles used for components of any such article.[319]

At first glance, this definition may seem to legally encompass GE food animals, as they are used for food. But this classification raises concerns regarding under-regulation. The drug approval process requires extensive premarket testing, including animal and human trials with strict scientific standards at each stage.[320] In contrast, most food products do not undergo an equivalent premarket approval process.[321] Even dietary supplements do not require FDA premarket approval for

---

318. *See generally supra* Part III.

319. 21 U.S.C. § 321(f).

320 . *See Development & Approval Process*, U.S. FOOD & DRUG ADMIN., https://www.fda.gov/drugs/development-approval-process-drugs [https://perma.cc/VBV2-VXCE].

321. Grossman, *supra* note 21, at 1129–30.

safety or efficacy.[322] According to the FDA, this is because, "unlike drug products that must be proven safe and effective for their intended use before marketing, there are no provisions in the law for [the] FDA to 'approve' dietary supplements for safety or effectiveness before they reach the consumer."[323] If GE food animals were classified as food, they could be under-regulated, lacking safety assessments. While market forces and liability concerns may provide some level of self-regulation[324] — as developers would be responsible for ensuring consumer safety — this approach could shift the regulatory spectrum too far in the opposite direction, mirroring the deficiencies of the current drug-based model. Therefore, a purely food-based regulatory approach may not strike the appropriate balance between safety oversight and technological innovation.[325]

Another obstacle to reclassifying GE food animals as food is jurisdictional fragmentation.[326] While the FDA regulates food safety, it does not regulate all food products. The USDA oversees three food categories, including meat, poultry, and certain egg products;[327] the safety of livestock production through APHIS;[328] and some aspects of biotechnology in agricultural crops, but not in animals.[329] Conversely, the FDA regulates all other foods, including seafood and dairy products, except for ictalurid catfishes, which fall under the USDA's

---

322. *Id.* at 1141.

323. Birdsall, *supra* note 86, at 266; *see also Questions and Answers on Dietary Supplements*, U.S. FOOD & DRUG ADMIN., https://www.fda.gov/food/information-consumers-using-dietary-supplements/questions-and-answers-dietary-supplements [https://perma.cc/YQL7-6K87]; 21 C.F.R. §190.6 (2010).

324. *See, e.g.*, Timothy D. Lytton, *Using Tort Litigation To Enhance Regulatory Policy Making: Evaluating Climate-Change Litigation of Lessons from Gun-Industry and Clergy-Sexual-Abuse Lawsuits*, 86 TEX. L. REV. 1837, 1838 (2008) (discussing how litigation might be used as a means of addressing climate change). More fundamentally, if there were a serious flaw in the technology, the animal would likely become ill or die, rendering it unfit for sale.

325. One possible approach to ensuring safety without excessive regulatory barriers is to rely on the FDA's adulteration authority under the Food Safety Modernization Act and the FDCA. *Sampling To Protect the Food Supply*, U.S. FOOD & DRUG ADMIN., https://www.fda.gov/food/compliance-enforcement-food/sampling-protect-food-supply [https://perma.cc/UJ7R-T26M] ("The FDA collects samples of food products ready to go to market, as well as in-process and raw ingredient samples, to ensure they don't reach consumers with harmful contaminants, or to verify that they contain ingredients at levels as declared on product labeling."). This is a post-market surveillance model that may be effective for conventional food safety enforcement, but it presents challenges when applied to GE food animals. Without a structured monitoring mechanism, regulatory oversight may be hard to implement.

326. The 2017 Coordinated Framework had established a similar jurisdictional fragmentation about biotechnology. *See* 2017 Coordinated Framework, *supra* note 15, at 27–32.

327. Federal Meat Inspection Act, 21 U.S.C. § 601; Poultry Products Inspection Act, 21 U.S.C. § 451; Egg Products Inspection Act, 21 U.S.C. § 1031.

328. Animal Health Protection Act, 7 U.S.C. § 8301.

329. 2017 Coordinated Framework, *supra* note 15, at 27.

purview.[330] This jurisdictional split raises serious practical issues if GE food animals were to be classified as food. The FDA would lack authority over GE meat, poultry, and certain egg products, creating a disjointed regulatory framework where different agencies regulate different GE food animals based on their species and final use rather than their underlying genetic modifications.

While the USDA could theoretically regulate GE food animals under APHIS by leveraging its authority over animal health and disease risks,[331] this would still fail to provide a coherent, centralized regulatory structure.[332] Given that regulatory uncertainty has already posed a significant barrier to innovation, adding multiple regulatory agencies into the mix may exacerbate existing inefficiencies rather than resolve them. The experience with cell-cultured meat illustrates this problem. Under the current framework, the FDA oversees the early stages of production prior to the development of harvestable tissue, while the USDA assumes authority once the product reaches a stage resembling conventional meat, including oversight of harvesting, processing, and labeling.[333] Scholars have argued that this division of responsibility is unnecessary and poorly suited to the underlying technology, creating regulatory complexity.[334] Rather than providing clarity, overlapping jurisdiction may therefore complicate the regulatory pathway and impose additional burdens on emerging industries.

B. Food Additives

Another option is classifying GE food animals as food additives by invoking the Delaney Amendment (also known as the Food Additives Amendment) to the FDCA,[335] which established food additive regulations. Food additives serve various functions, including preserving freshness and enhancing flavor or texture.[336] This

330. Food, Conservation, and Energy Act of 2008, Pub. L. No. 110–246, 122 Stat. 1651; Agricultural Act of 2014, Pub. L. No 113–79, 128 Stat. 649.

331. *See supra* note 127 for a description of USDA authority.

332. For example, the FDA would still regulate fish (except catfish).

333. *Formal Agreement Between FDA and USDA Regarding Oversight of Human Food Produced Using Animal Cell Technology Derived from Cell Lines of USDA-Amenable Species*, U.S. FOOD & DRUG ADMIN., https://www.fda.gov/food/human-food-made-cultured-animal-cells/formal-agreement-between-fda-and-usda-regarding-oversight-human-food-produced-using-animal-cell [https://perma.cc/KJ97-WQAZ].

334. *See, e.g.*, Tammi S. Etheridge, *What's the Beef? The FDA, USDA, and Cell-Cultured Meat*, 78 WASH. & LEE L. REV. 1729, 1756–57 (2022).

335. Food Additives Amendment of 1958, Pub. L. No. 85-929, 72 Stat. 1784; NEIL FORTIN, FOOD REGULATION: LAW, SCIENCE, POLICY AND PRACTICE 18 (2017).

336. *Understanding How the FDA Regulates Food Additives and GRAS Ingredients*, U.S. FOOD & DRUG ADMIN., https://www.fda.gov/food/food-additives-and-gras-ingredients-information-consumers/understanding-how-fda-regulates-food-additives-and-gras-ingredients [https://perma.cc/68LU-FD9P].

regulatory model shares elements of both the food and drug paradigms. Food additives may be introduced into food only under two conditions: inclusion on the FDA's Generally Recognized as Safe ("GRAS") list, or premarket approval through a food additive petition, which requires extensive scientific data on safety.[337] In particular, the scientific evaluation process for food additives mirrors that of new drug approvals.[338] Thus, classifying GE food animals, or their IGAs, as food additives would not change much. It would likely introduce new uncertainties and necessitate new guidance documents, which may ultimately copy the FDA's current approach under the drug framework.[339]

C. Enforcement Discretion

GE animals are usually subject to premarket approval. The FDA offers an exception to this rule through "enforcement discretion" in cases where the risk is deemed low.[340] A third possible option is the expansion of the FDA's enforcement discretion to more cases. And in expanding enforcement discretion, the FDA can include additional categories of products that require no application submission or are exempt from the full regulatory process. The FDA has previously exercised enforcement discretion in cases where genetic modifications mimic naturally occurring mutations (e.g., "slick" cattle).[341] This approach would allow for targeted regulatory relief without requiring major legislative changes.[342]

However, enforcement discretion presents challenges. First, it might create regulatory uncertainty. Without clear criteria for enforcement discretion, developers may not be able to reliably plan on how to bring their product to market, which in turn can deter investment.[343] Second, there might be agency reluctance to pursue this path. Conversations with FDA officials indicate strong institutional support for the current framework, making a broad shift toward discretion unlikely.[344] Third, products regulated under enforcement discretion must still be labeled as containing an "unapproved drug."[345]

---

337. *See* 21 C.F.R. §§ 171–172 (2024).

338. *See* FORTIN, *supra* note 335, at 203–04.

339. *See id.*

340. GUIDANCE 187A, *supra* note 17, at 5.

341. U.S. FOOD & DRUG ADMIN., *supra* note 10.

342. Because these are cases where the FDA determines the risk to be low, the full procedure is deemed unnecessary. Enforcement discretion allows the agency to make exceptions.

343. *See* discussion *supra* Section III.B. Certainty is critical for fostering innovation and encouraging investors to commit funding to new projects.

344. FDA Officials Interview, *supra* note 152.

345. NAT'L SEC. COMM'N ON EMERGING BIOTECH., *Modernizing Animal Biotechnology Regulation*, FUTURE BIOTECH. REG., Jan. 2026, at 2.

This designation may create trade barriers and foster consumer aversion due to the stigmatizing nature of this label. [346] Given these considerations, enforcement discretion may not be a viable long-term solution.

D. New Legislation

The most effective long-term solution may be legislative reform by creating a dedicated regulatory framework for GE food animals or for biotechnology products in general. The United States has relied on decades-old laws to regulate new technologies, but this approach fails to adequately address modern advancements in genetic engineering. In theory, Congress could enact new legislation to establish a distinct approval process for IGAs in food animals, a tiered risk assessment model that differentiates low-risk genetic modifications from high-risk alterations, and a clear jurisdictional framework, ensuring coherent and predictable oversight. Legislative and political obstacles may delay such reforms, and there is no guarantee that any new framework will ultimately prove effective. Nevertheless, pursuing new legislation remains the preferable course of action for several reasons.

First, the current regulatory framework appears increasingly ill-suited to the industry, as reflected in the limited number of approved products, stakeholder concerns, and the overall pace of development. New legislation offers a meaningful opportunity for improvement. Although the legislative process may take time, the current regime can continue to operate in the interim.

Second, new legislation would reduce uncertainty and promote long-term regulatory stability. By contrast, the current approach preserves and, in some cases, exacerbates uncertainty. Biotechnology continues to evolve rapidly, and emerging technologies may fit even less comfortably within existing statutory definitions. This dynamic has already been observed with the development of techniques such as CRISPR/Cas9, which prompted the FDA to update its 2009 guidance in 2017 to clarify their regulatory status. [347] As new technologies emerge, similar uncertainties are likely to recur, requiring further guidance, regulatory interpretation, and adjustment by stakeholders. [348] A legislative framework specifically designed to

346. *Id.*

347. *See* GUIDANCE 187A, *supra* note 17, at 2 ("This guidance clarifies the scope of the version of GFI #187 FDA issued in 2009 to include IGAs created with these newer technologies and thus includes IGAs produced using rDNA technology as well as newer genome editing and other technologies.").

348. *Id.* ("We anticipate that, over time, IGAs created with other technologies will arise. This policy is being implemented based on the Agency's current understanding of these products and their risk(s). We may update this guidance as needed, should our scientific

address biotechnology could mitigate these recurring uncertainties by providing more adaptable rules.

Third, the current regulatory landscape for biotechnology is fragmented and lacks a coherent statutory foundation. Different technologies — such as GE animals, GE plants, and cloning — are regulated under distinct and sometimes inconsistent frameworks. At the same time, similar regulatory approaches are often applied to technologies with fundamentally different uses. A comprehensive legislative approach could instead address these technologies explicitly and coherently.

The United States must decide whether to take a proactive approach, crafting a modern, regulatory structure. To do so, policymakers can look to other countries for potential regulatory models.

Argentina initiated regulations for genetically modified organisms ("GMOs") in 1991.[349] They apply a case-by-case evaluation based on scientific criteria, data quality, familiarity, and history of safe use.[350] Two types of assessments are conducted: (1) a biosafety evaluation for research and contained production and (2) an environmental risk assessment for commercial release.[351] All applications undergo review by multiple regulatory bodies, resulting in non-binding reports — which are then submitted to the Undersecretary of Agricultural Markets for final consideration.[352] But the Argentinian system is unique because it examines on a case-by-case basis whether products derived from New Breeding Techniques ("NBTs") — similar to CRISPR — are GMOs or not.[353] Argentina established the world's first regulatory framework for products derived from NBTs in 2015.[354] The regulatory procedure is determined by the final genetic change — specifically, whether it results in a new combination of genetic material.[355] This standard distinguishes between transgenic changes (introducing genes from another organism) and non-transgenic changes (modifying genes within the animal's own genome). If a product is classified as non-

---

understanding of these products and their risk(s) change and/or to reflect newer technologies as well as improvements to existing technologies.").

349. Eric Hallerman, Justin Bredlau, Luiz Sergio A. Camargo, Maria Lucia Zaidan Dalgi, Margaret Karembu, Daniel Kovich et al., *Enabling Regulatory Policy Globally Will Promote Realization of the Potential of Animal Biotechnology*, 5 CABI AGRIC. & BIOSCI. 1, 14 (2024).

350. *Id.*

351. *Id.*

352. *Id.* at 14–15.

353. Maria Florencia Goberna, Argentina Regulatory — New Breeding Techniques (NBT), PowerPoint Presentation at the 4th International Workshop on Regulatory Approaches for Agricultural Applications of Animal Biotechnologies, ISAAA (Sep. 14, 2022), https://www.isaaa.org/kc/proceedings/animalbiotechnology/2022-09-12-4th-intl-workshop/session07/42Goberna/default.asp [https://perma.cc/6H5T-4D2X].

354. *Id.*

355. *Id.*

GMO due to its non-transgenic nature, it is regulated as a product of conventional breeding and is exempt from the extensive evaluations required for GMOs.[356] This approach enables developers to anticipate costs and timelines from as early as the design phase.[357]

Brazil's regulatory system also differentiates between GMOs and non-GMOs.[358] Products developed through NBTs undergo a case-by-case analysis to determine their classification as GMOs.[359] For a product to be deemed non-GMO, developers must demonstrate that it lacks recombinant DNA/RNA or any DNA/RNA that is novel to the species, and that it has no significant unintended effects.[360] As is the case with its Argentinian counterpart, Brazil's regulatory system essentially distinguishes between a transgenic change (GMOs) and a non-transgenic change (non-GMOs). As of July 2022, Brazil had classified twenty-seven GE products as non-GMOs, which are mostly microorganisms but also include crops such as maize, soybean, and sugarcane.[361] In animals, myostatin-knockout Nile tilapia (with enhanced growth rate and feed efficiency) and semen from a myostatin-knockout bull (with increased muscle mass) were classified as non-GMO.[362] Similarly, a bull and a heifer with prolactin receptor mutations producing the "slick" hair trait were also deemed non-GMO.[363] These products are exempt from GMO regulations but still require approval from the relevant regulatory agency — environmental, animal health, or human health — depending upon the product type.[364]

The main regulatory development in the Argentine and Brazilian systems is the distinction they draw between GMO and non-GMO animals. While it may be too early to fully assess their long-term impact, we can still learn from their models. Under such an approach, transgenic modifications would be subject to more stringent regulatory

---

356. *Id.*

357. Hallerman et al., *supra* note 349, at 18 ("The advantages of the Argentine regulatory framework are that it increases the availability of information, reduces uncertainty among both developers and users, facilitates the decision-making process and diffusion of innovation, and improves the predictability of regulatory costs for innovative products. Noting the number of developments and consultations carried out, Goberna et al. (2022) showed that the speed of innovation of these technologies was increasing, giving more opportunity to local developers who showed interest in generating products involving different species and phenotypes.") (citations omitted).

358. Luiz Sergio A. Camargo & Rubens Nascimento, Regulatory Experiences with Genome Edited Animals in Brazil, PowerPoint Presentation at the 4th International Workshop on Regulatory Approaches for Agricultural Applications of Animal Biotechnologies, ISAAA (Sep. 12–16, 2022), https://www.isaaa.org/kc/proceedings/animalbiotechnology/2022-09-12-4th-intl-workshop/session09/58Camargo/default.asp [https://perma.cc/X2YS-ZLQS].

359. *Id.*

360. Hallerman et al., *supra* note 349, at 15.

361. *Id.*

362. *Id.* at 15–16.

363. *Id.*

364. *Id.* at 16.

oversight, while non-transgenic (cisgenic) alterations would face significantly lighter or no regulation.

However, this model is not without shortcomings. First and foremost, it relies on a categorical distinction between cisgenic and transgenic changes that does not necessarily correspond to actual risk.[365] In practice, cisgenic modifications can raise concerns similar to those associated with transgenic changes.[366] As a result, a framework based solely on the origin of the genetic alteration risks both overregulating low-risk products and under-regulating higher-risk ones. A related concern is that this framework is a binary, all-or-nothing system. It creates a sharp divide between minimal oversight and highly burdensome regulation, rather than a spectrum of regulatory tools. Such rigidity is ill-suited to the wide range of risks associated with different genetic alterations. A more effective system would likely adopt a tiered approach, incorporating some level of oversight for lower-risk changes — such as monitoring, reporting requirements, validation of targeted genetic edits, and basic animal health assessments — while reserving more intensive review for higher-risk modifications.

It is worth noting that the system in the United States suffers from similar shortcomings. In practice, the FDA regulates nearly all GE food animals through a lengthy process, regardless of actual product risk.[367] It does not allow regulatory flexibility and employs an all-or-nothing approach. A GE food animal is either a drug, or the FDA exercises enforcement discretion with essentially no regulation. Compared to the Argentina-Brazil model, the United States' approach errs much more on the side of overregulation rather than under-regulation. It is also less stable, as it relies heavily on FDA guidance, which the FDA can change easily.[368]

The Latin American model, by contrast, offers a key advantage of fostering innovation and regulatory certainty. Research suggests that Argentina's approach has boosted industry activity and research applications.[369] In the short term, and at least in theory, the United States could move in a similar direction without immediate legislative reform by expanding the use of enforcement discretion — for example, by systematically exempting certain genetic modifications for specific

365. *See* S.N. Vasudevan, S.K. Pooja, Thota Joseph Raju & C.S. Damini, *Cisgenics and Intragenics: Boon or Bane for Crop Improvement*, 14 FRONTIERS PLANT SCI. 1 (2023); *see also* NAT'L ACADS. OF SCIS., ENG'G & MED., *supra* note 12, at 501 ("All technologies for improving plant genetics have the potential to change foods in ways that raise safety issues."); Dennis Eriksson, Sten Stymne & Jan K. Schjoerring, *The Slippery Slope of Cisgenesis*, 32 NATURE BIOTECH. 727, 727 (2014).

366. *Id.*; *see also* Alan McHughen, *A Critical Assessment of Regulatory Triggers for Products of Biotechnology: Product vs. Process*, 7 GM CROPS & FOOD 125, 150–51 (2016).

367. *See* GUIDANCE 187A, *supra* note 17, at 4–5.

368. *See supra* Section III.A.2.

369. *See* Hallerman et al., *supra* note 349, at 18.

traits or in specific locations in the genome. However, such an approach would remain imperfect. Expanding enforcement discretion would still preserve the underlying binary structure, leaving some products subject to full approval while placing other products outside regulatory oversight. As a result, it would fail to establish a truly risk-based or flexible framework. In addition, it would continue to rely on agency discretion that may change over time while creating instability.

Accordingly, the United States must move beyond its current ad hoc and binary approach toward a deliberate, coherent regulatory pathway for GE food animals. A more effective regulatory system should incorporate a tiered oversight model with a broader range of regulatory tools that would potentially introduce new statutory categories with graduated levels of oversight. Given the FDA's limited maneuverability under the FDCA, and its reluctance to deviate from its finalized guidance and its policy, meaningful long-term reform likely requires congressional intervention. Only a new statutory framework — one specifically tailored to the unique biological and economic realities of animal biotechnology — can reconcile the need for rigorous safety oversight with agricultural innovation.

VI. CONCLUSION

The regulation of GE food animals in the United States remains anchored in an outdated statutory framework that treats genomic alterations as "drugs" under the FDCA — a classification that neither aligns with the statutory text nor reflects the realities of modern agricultural biotechnology. As this Article has shown, this approach imposes disproportionate regulatory burdens, narrowing the field of participants and limiting the diversity of traits explored. Small companies, startups, and academic researchers are particularly constrained, and the result is a chilling effect on a field that could otherwise advance food security, environmental sustainability, and animal welfare.

The legal analysis presented here demonstrates that the "drug" classification is a regulatory workaround born of historical context rather than a deliberate legislative decision. The statutory language, legislative history, and caselaw offer little support for treating genomic alterations as regulated "articles," especially when the end product is intended for food consumption rather than therapeutic use. While the FDA's precautionary stance was shaped by early public skepticism toward biotechnology, the accumulation of scientific knowledge and regulatory experience now justify a recalibrated, risk-proportionate framework.

The United States should replace its ad hoc approach to GE food animals with a regulatory pathway that moves beyond the binary choice

between drug approval and enforcement discretion. A more effective system would adopt tiered oversight, using a broader set of tools and potentially new statutory categories with graduated requirements. A tailored framework could set clear jurisdictional boundaries between federal agencies, streamline low-risk approvals, and preserve rigorous review for higher-risk applications.

Regulatory reform should be guided by scientific evidence, technological realities, and the imperative to balance safety with innovation. Without such change, the current model will continue to constrain the potential of GE food animals, forfeiting advancements that could deliver measurable benefits to the public, the environment, and the agricultural economy.

APPENDIX: LIST OF INTERVIEWEES

I. Academics:
   a. Alison Van Eenennaam: Researcher at University of California, Davis.
   b. Eric Hallerman: Researcher at Virginia Polytechnic Institute and State University.
   c. Jon Oatley: Researcher at Washington State University.

II. Industry:
   a. Clint Nesbitt: Global Director of Regulatory and External Affairs at Genus.
   b. Tad Sonstegard: Chief Science Officer of Acceligen.
   c. Mark Walton: Former Head of Regulatory Affairs at AquaBounty.

III. Governmental Officials:
   a. Two FDA Officials.
   b. Larisa Rudenko: Former CVM official.
   c. Diane Wray-Cahen: Former Senior Advisor for Animal Health and Production, and Animal Products, USDA Office of the Chief Scientist.