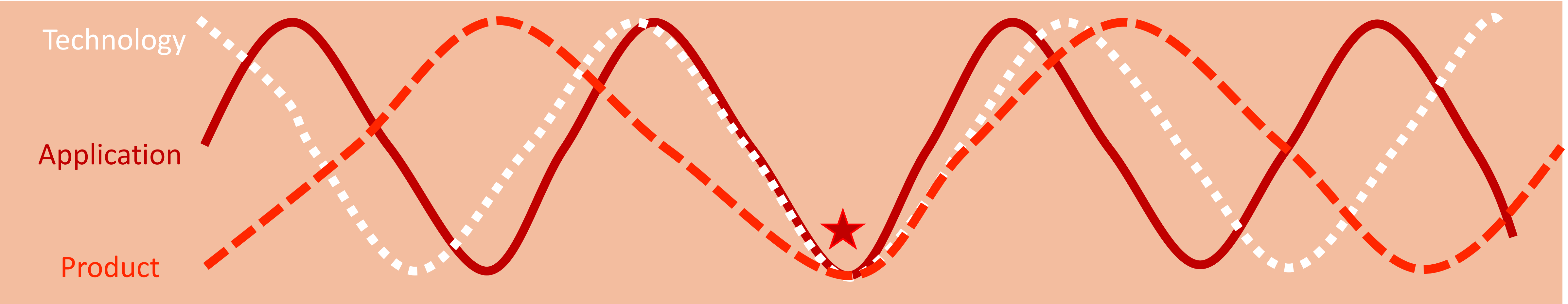
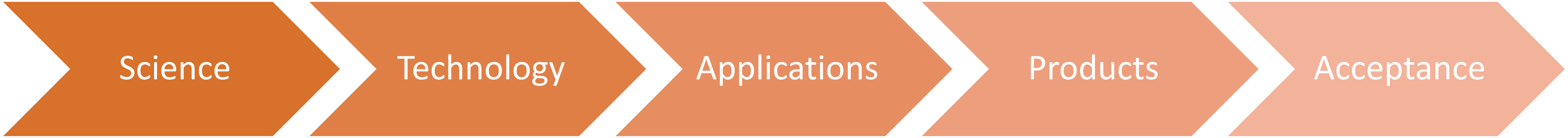
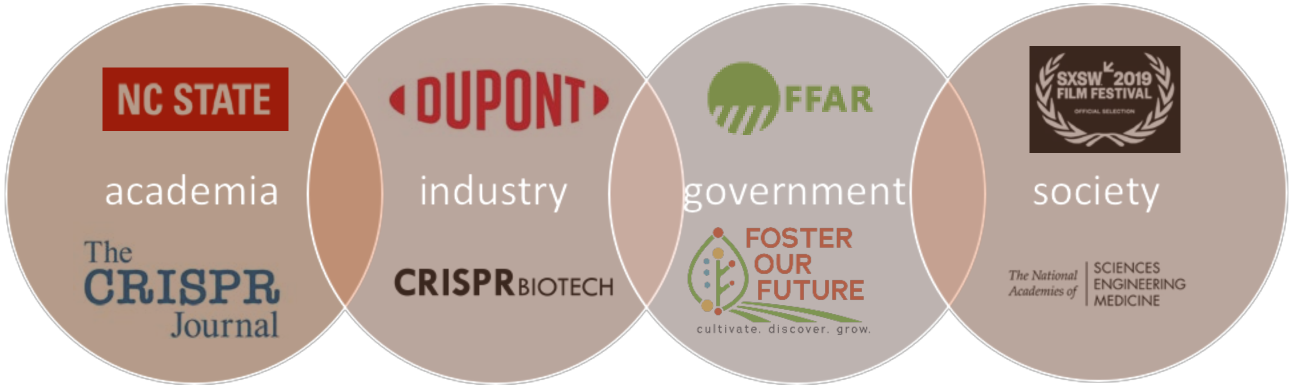
The CRISPR craze: managing disruptive genome editing technologies

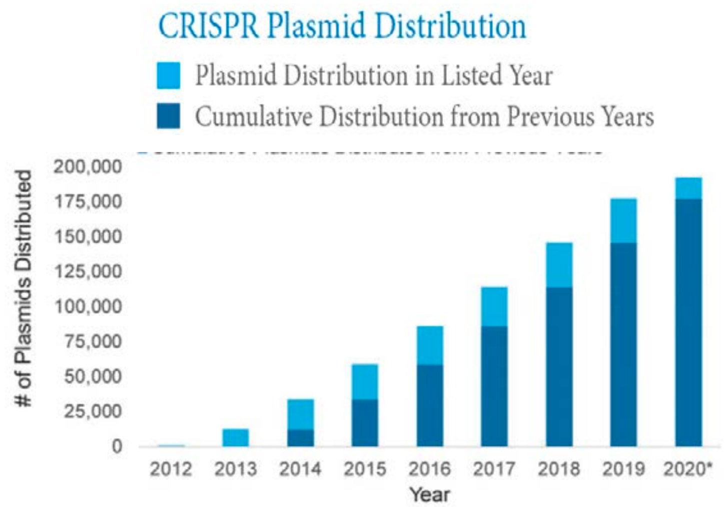
Rodolphe Barrangou | NC State | @CRISPRlab

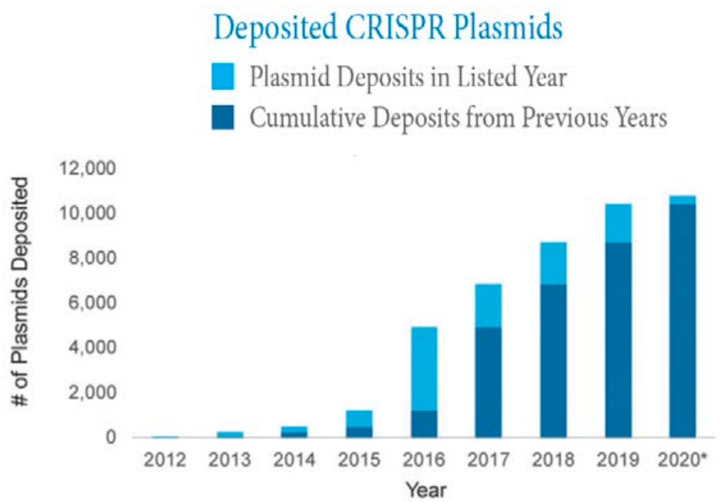


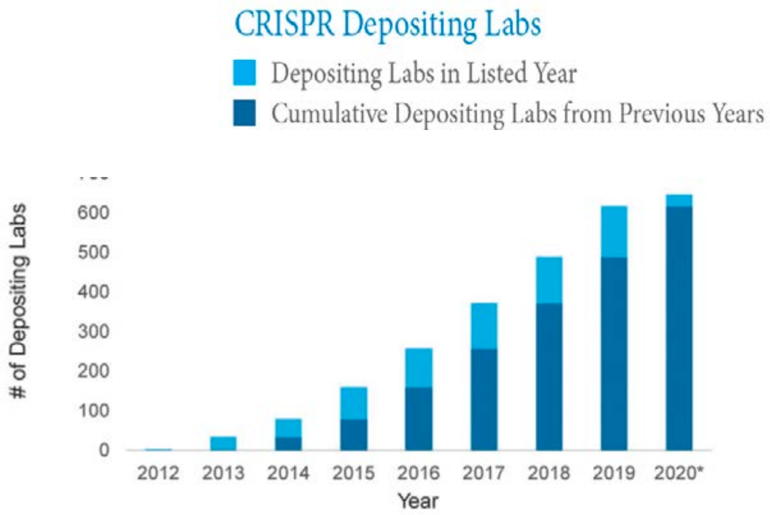




The Innovator’s dilemma



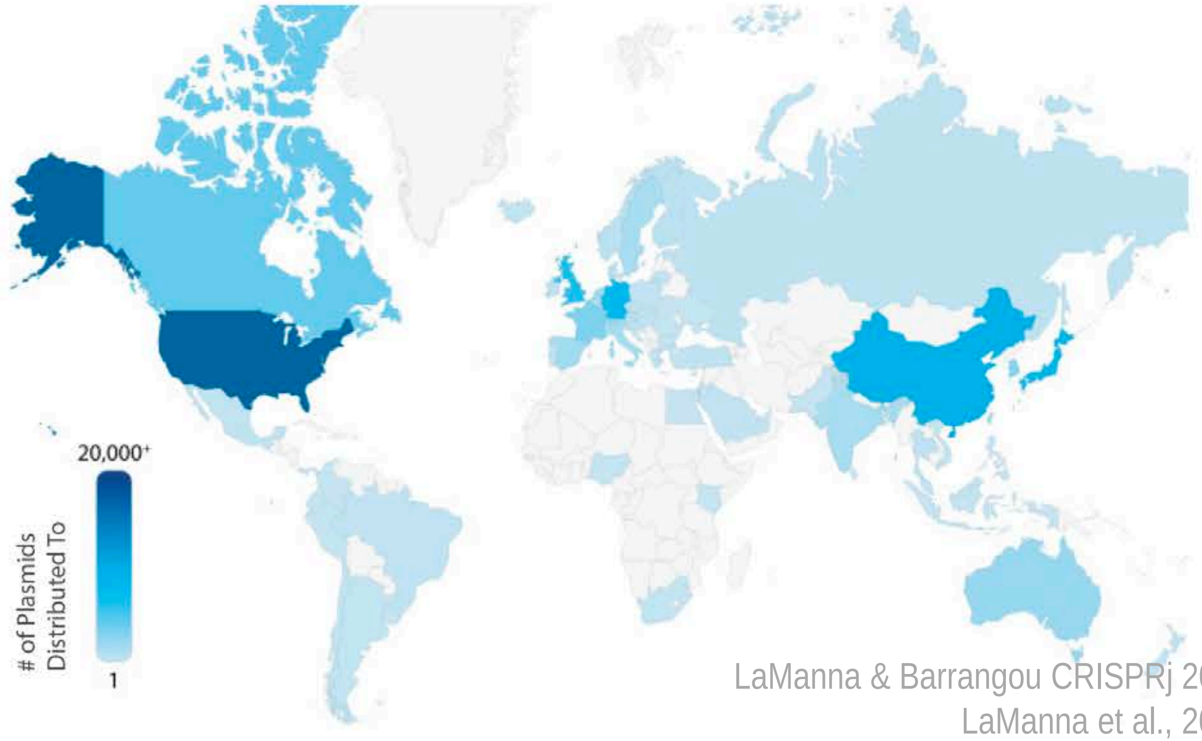




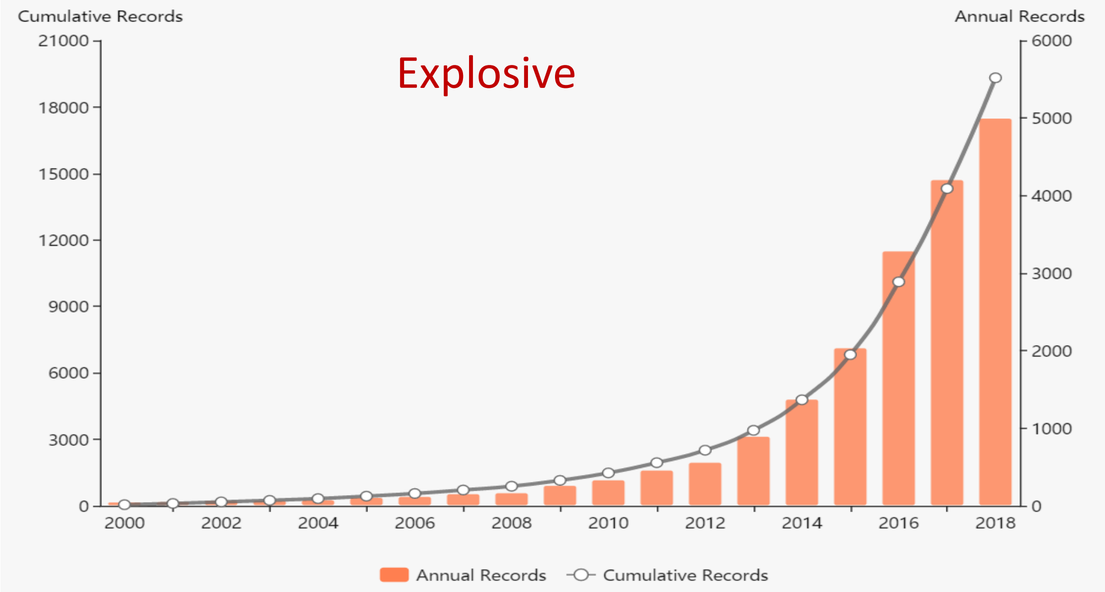
Where CRISPR Plasmids Were Deposited From

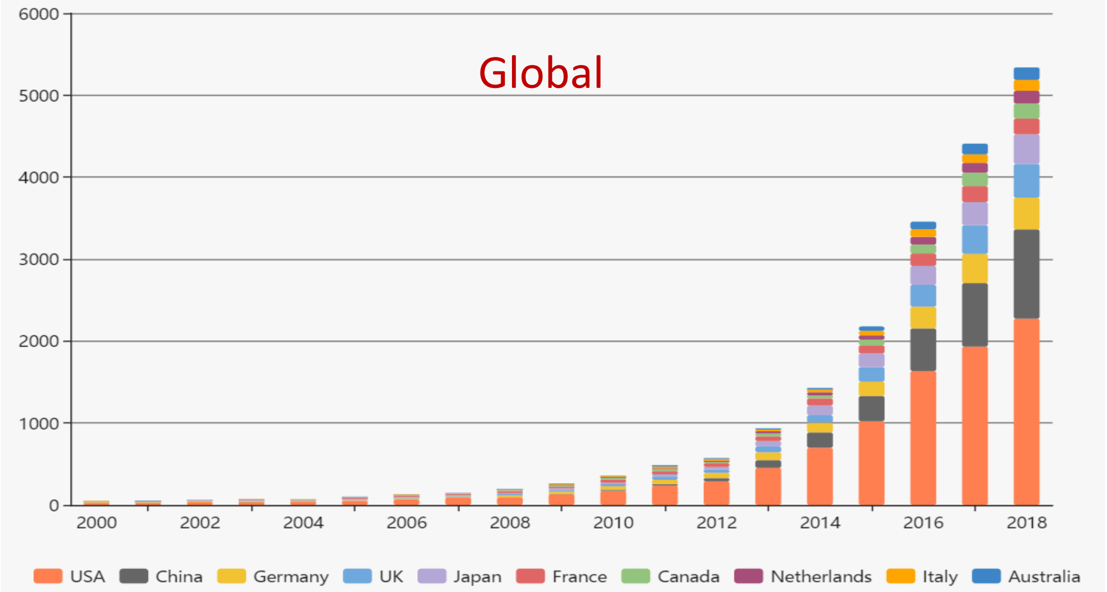
Living in a CRISPR world

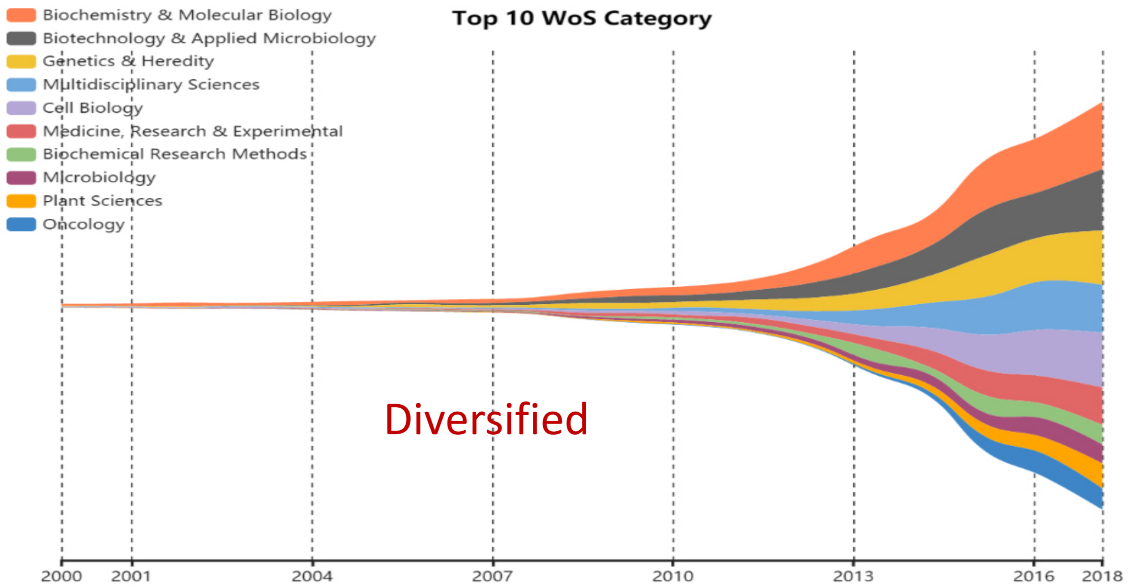
Where CRISPR Plasmids Were Distributed To

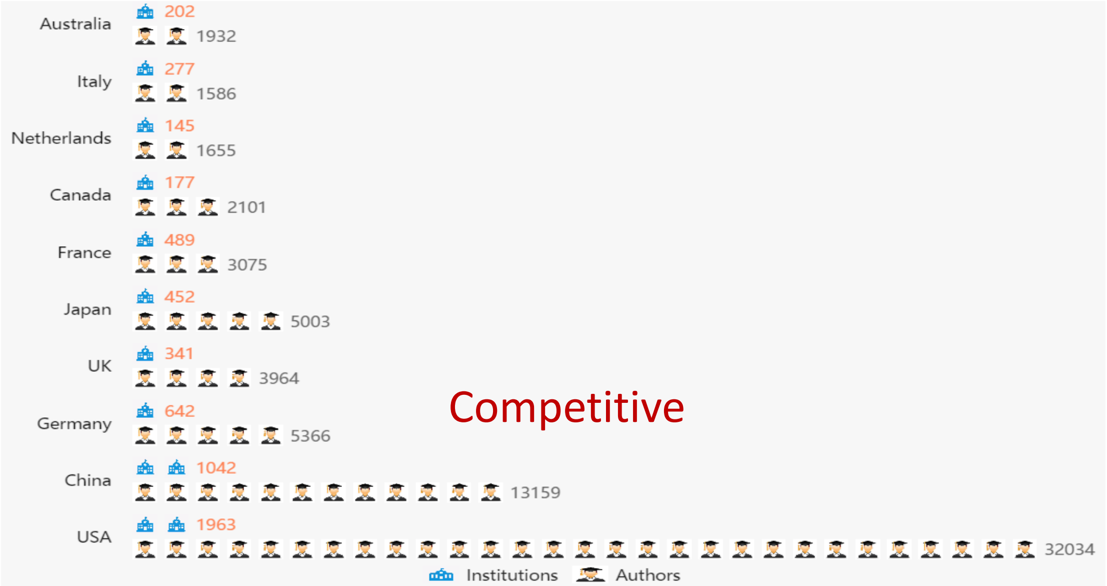


LaManna & Barrangou CRISPRj 2018
LaManna et al., 2020

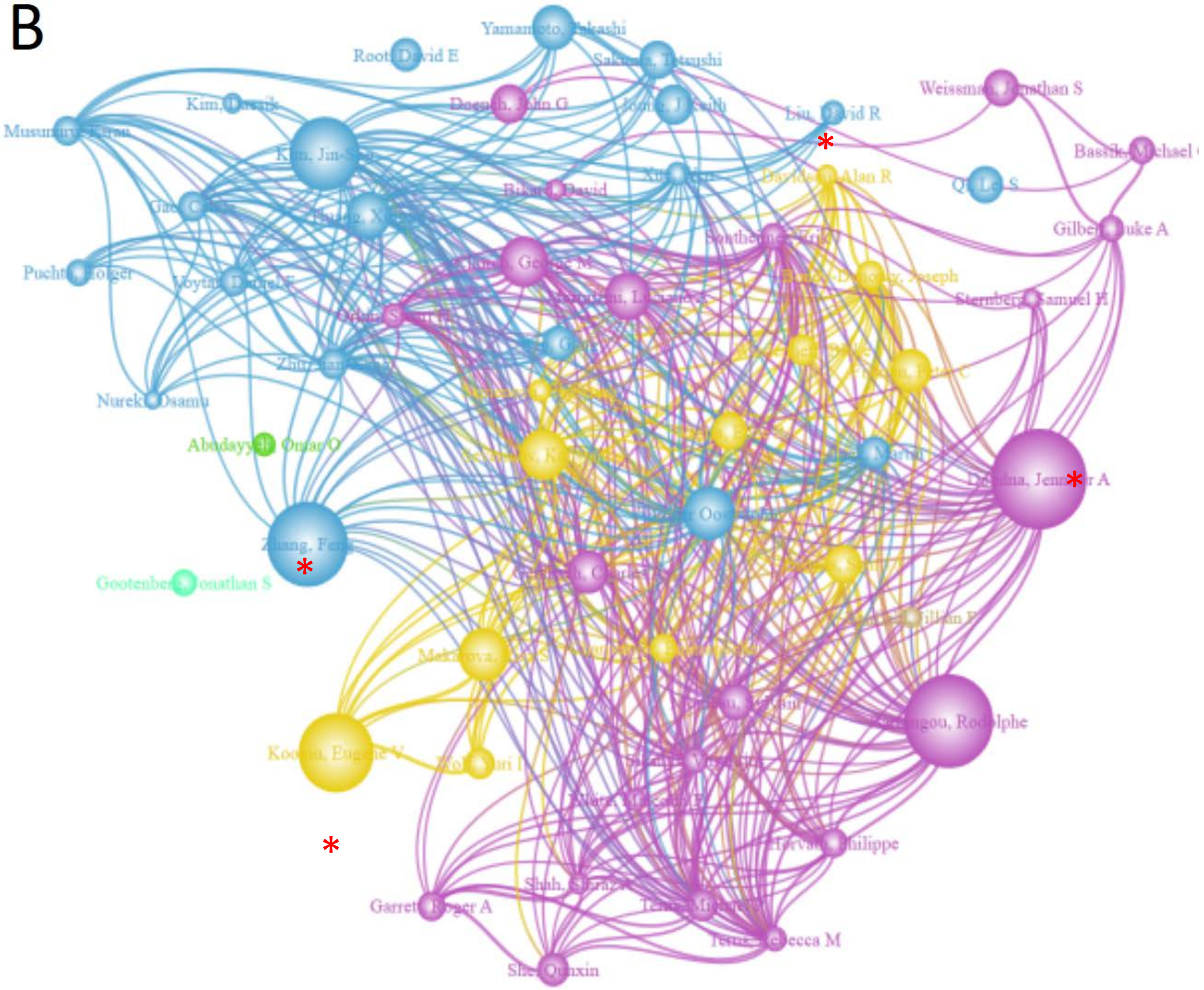

Explosive
Cumulative Records
Annual Records
21000
18000
15000
12000
9000
6000
3000
0
6000
5000
4000
3000
2000
1000
0
2000 2002 2004 2006 2008 2010 2012 2014 2016 2018
Annual Records
Cumulative Records


Global
6000
5000
4000
3000
2000
1000
0
2000 2002 2004 2006 2008 2010 2012 2014 2016 2018
USA
China
Germany
UK
Japan
France
Canada
Netherlands
Italy
Australia


Top 10 WoS Category
Diversified
Biochemistry & Molecular Biology
Biotechnology & Applied Microbiology
Genetics & Heredity
Multidisciplinary Sciences
Cell Biology
Medicine, Research & Experimental
Biochemical Research Methods
Microbiology
Plant Sciences
Oncology
2000 2001 2004 2007 2010 2013 2016 2018

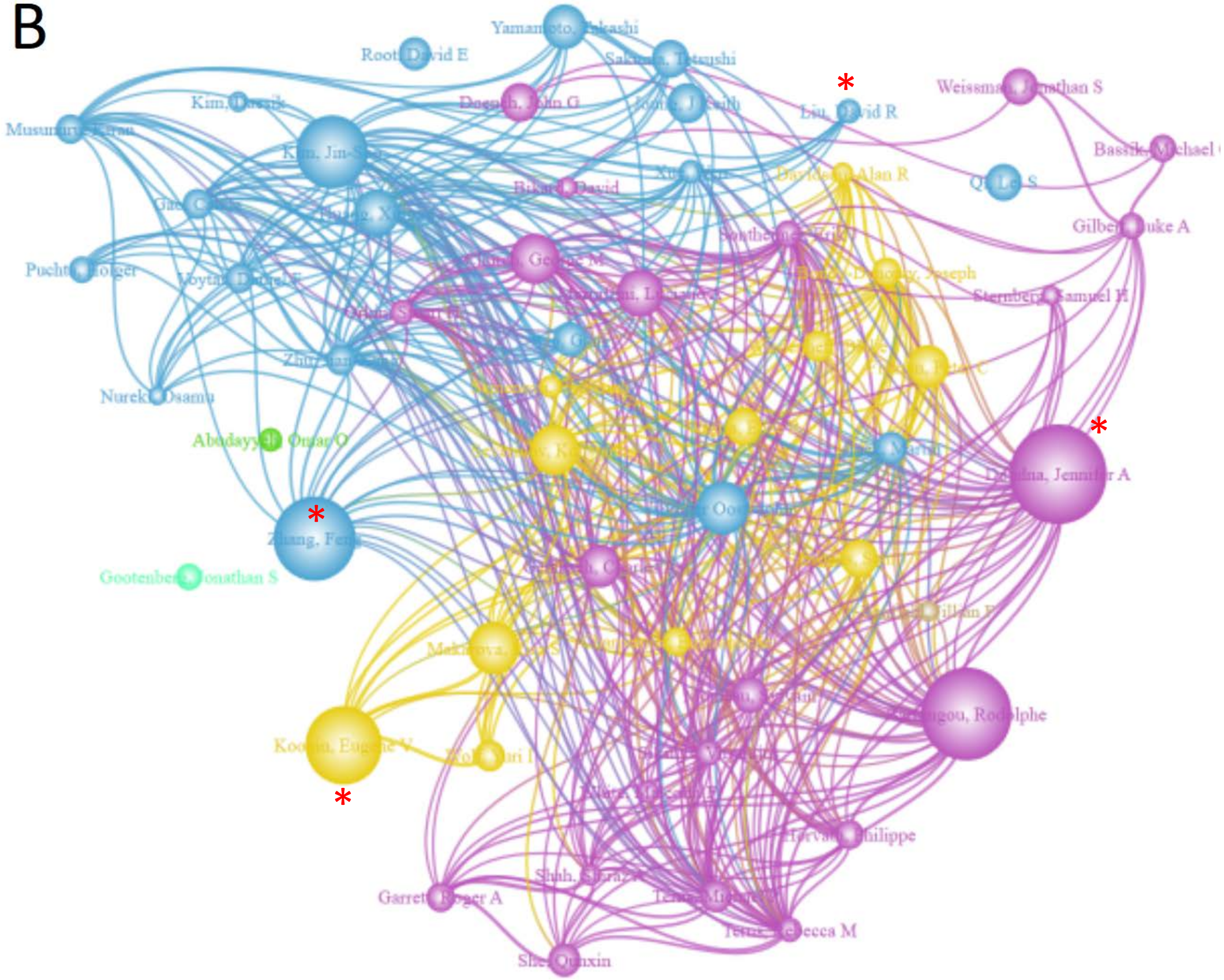

Competitive
Australia 202 1932
Italy 277 1586
Netherlands 145 1655
Canada 177 2101
France 489 3075
Japan 452 5003
UK 341 3964
Germany 642 5366
China 1042 13159
USA 1963 32034
Institutions
Authors

B



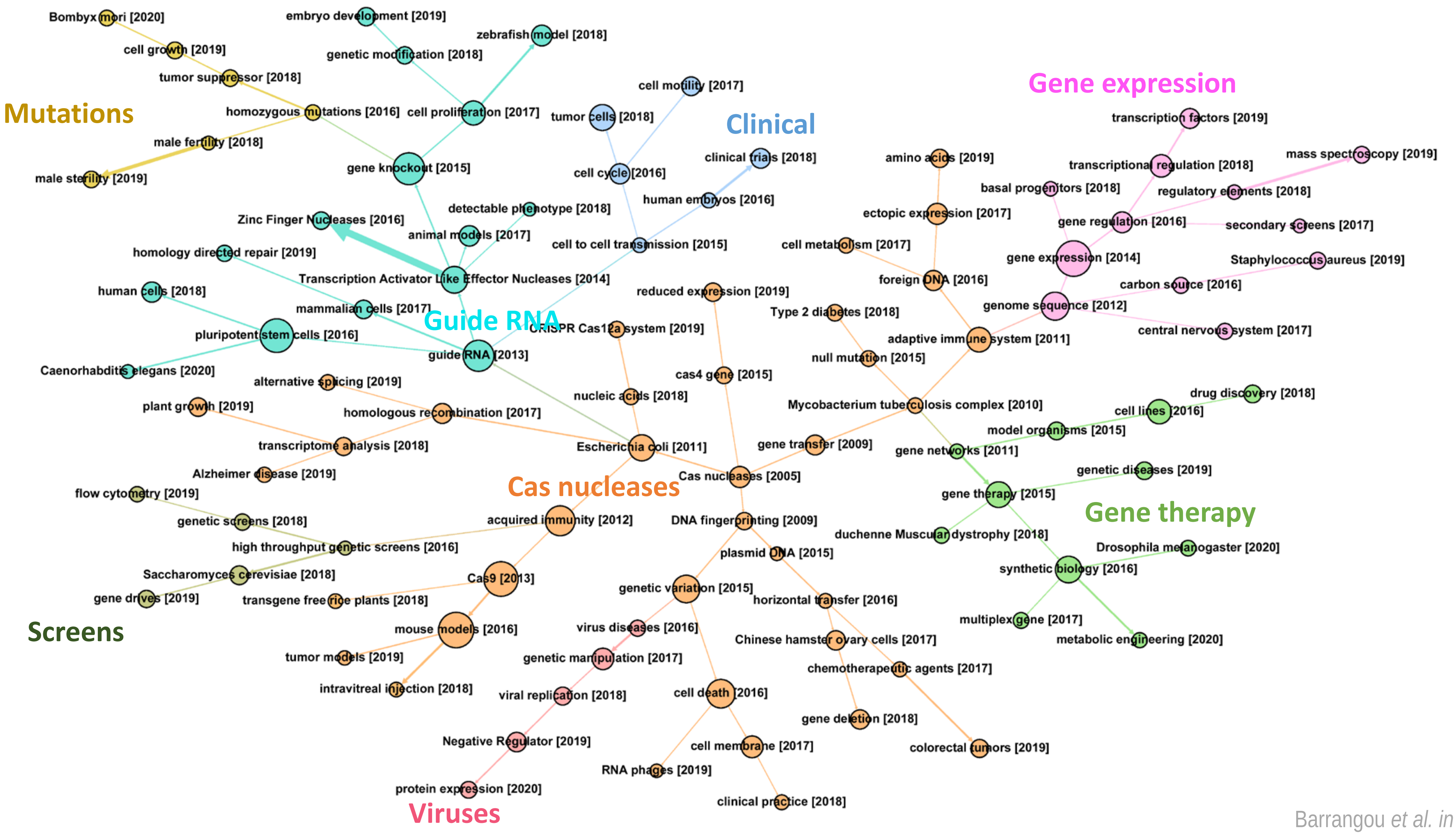
Co-authorships

B

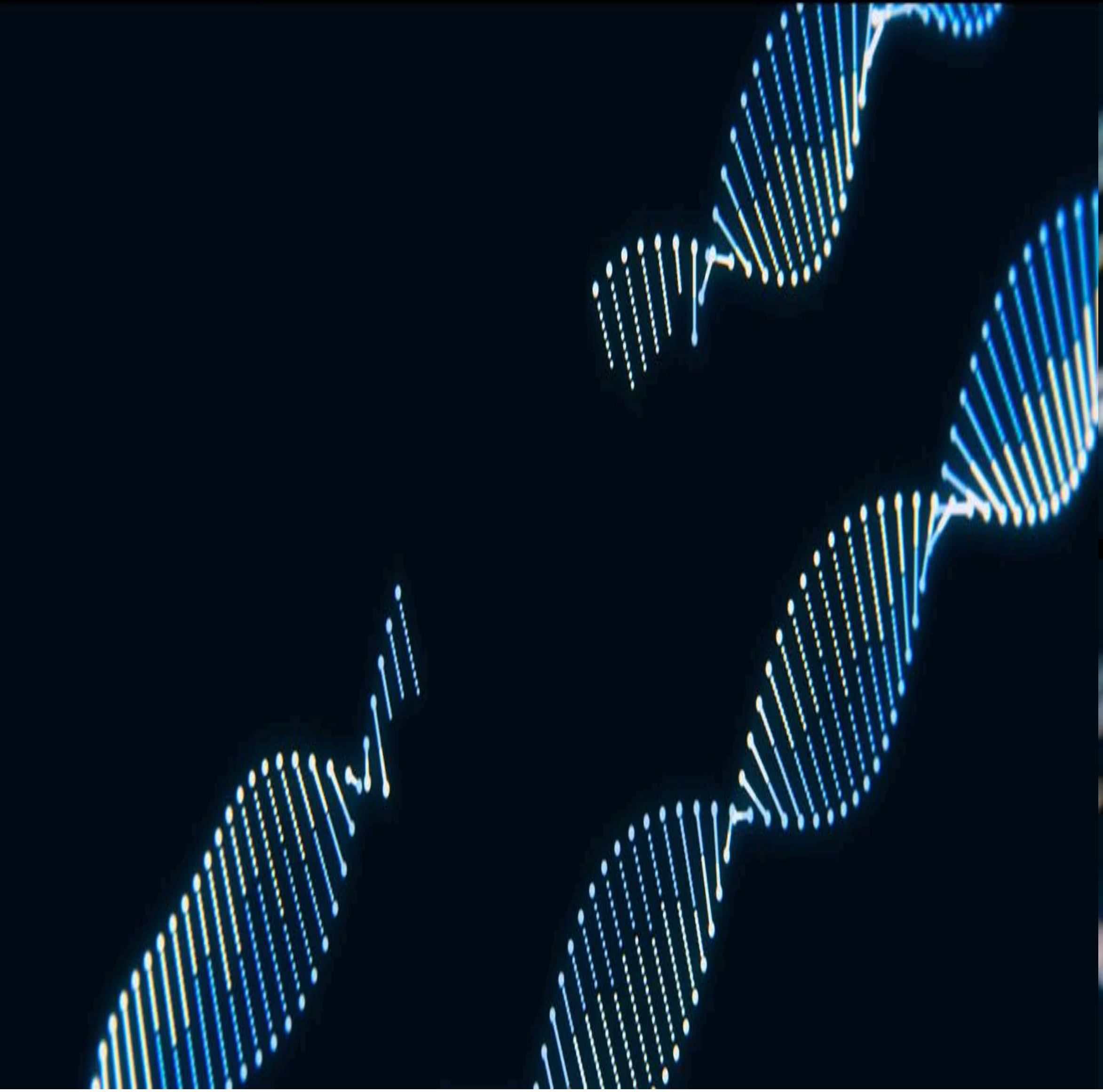


topics

Barrangou *et al. in review*

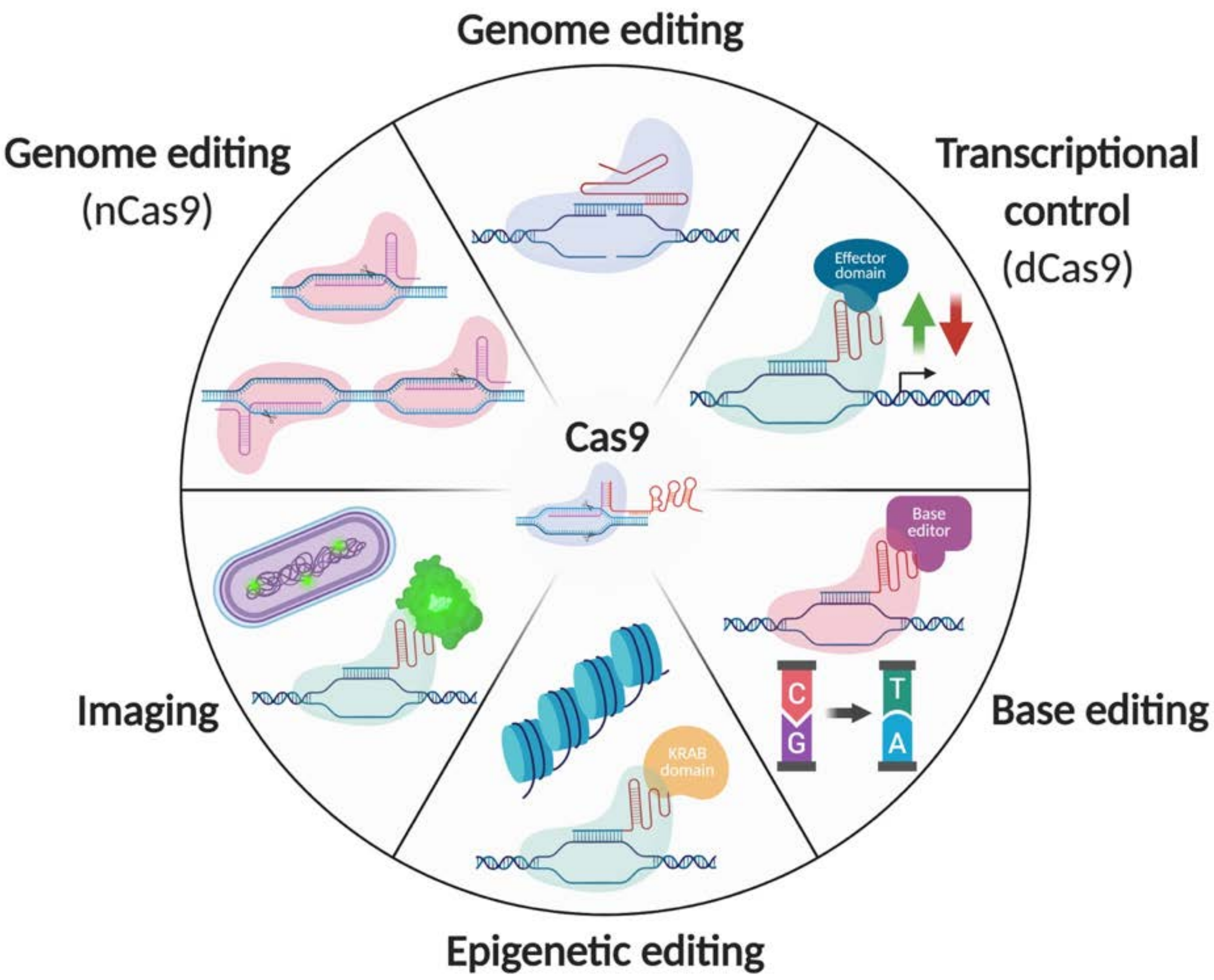


Barrangou *et al. in review*



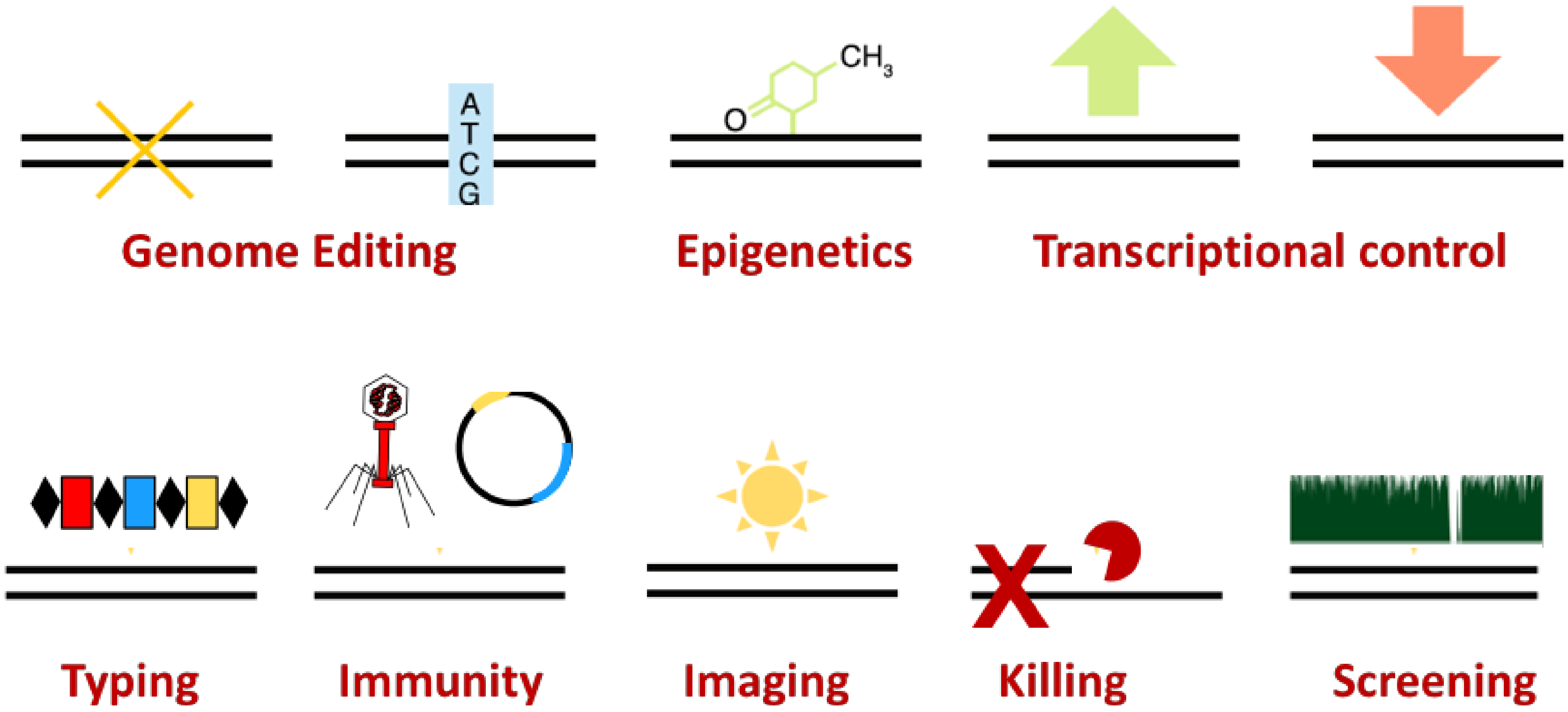
Genome editing

Barrangou & Doudna 2016



Genome Editing $^{2.0}$ Cas9, dCas9, nCas9

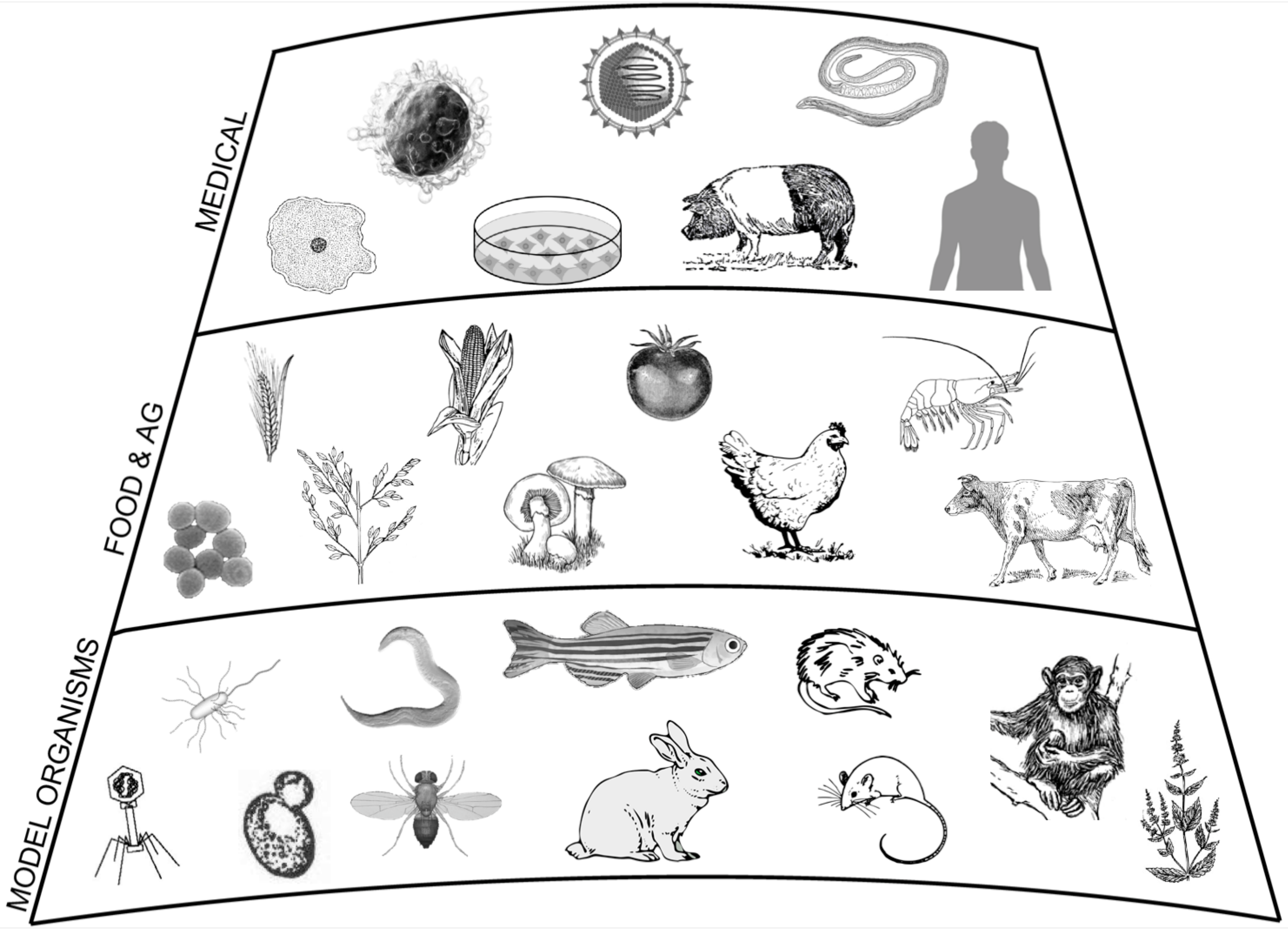
Roberts & Barrangou 2020



CRISPR$^{2.0}$ * Cas3 Cas9 Cas12 Cas13 CasTn

Illustration

Barrangou & Doudna 2016



The CRISPR zoo

Selle & Barrangou 2016
Gersbach & Barrangou 2018

CRISPR "technology" turns 7

Advantages

Programmable
Specific
Transferable
Efficient
Precise
Affordable
Quick
Multiplexable
Scalable

Caveats

Large (package/deliver)
PAM-dependent targeting
PAM diversity
Off target cleavage
Various efficiencies

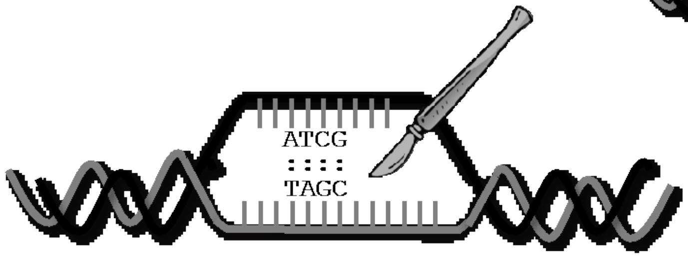
Opportunities

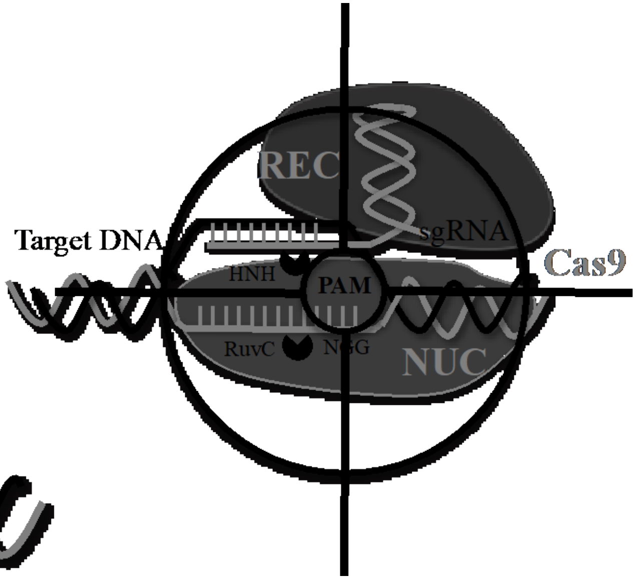
Guide design & composition
Cas engineering
Orthogonality
Biodiversity (eff, act, saf, tox, siz)
PAM diversity

DNA repair (cutting only front 50%)

Delivery

Electro/biolistic
Peptides/RNPs/RNA
Lipids/microinj.
Viruses/phagemids
Tissue/cell specific





Fields of use

RESEARCH

Tools
Guides
Enzymes
Software
Plasmids
Delivery
Kits
Primers
Cell lines

BIOTECHNOLOGY

Bacteria
Yeast
Algae

Food
Biomanufacturing
Household care
BioEnergy

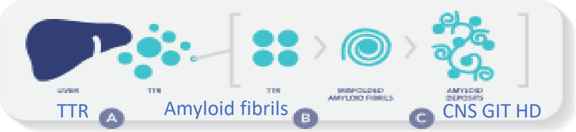
AGRICULTURE

Plants
Animals
Microbes
Forestry
Flowers & ornamentals
Aquaculture

THERAPEUTICS

Gene therapies
Antivirals & inf. disease
Microbiomes
Antimicrobials
Cell / immuno therapies
Xeno transplants
Invasive species/Drives
Diagnostics
Petcare

		Programs	Program Lead	Stage
In vivo	Genetic Disease	Transthyretin Amyloidosis	Intellia Therapeutics / REGENERON	Late Stage Preclinical
		Alpha-1 Antitrypsin Deficiency	Intellia Therapeutics	Preclinical
		Primary Hyperoxaluria Type 1	Intellia Therapeutics	Preclinical
ex vivo	Immuno-oncology	Acute Myeloid Leukemia	Intellia Therapeutics	Preclinical
		Undisclosed	NOVARTIS	Preclinical
	Hematology	Sickle Cell Disease	NOVARTIS	Late Stage Preclinical
	Autoimmune Diseases	Undisclosed	Intellia Therapeutics	Preclinical



Intellia THERAPEUTICS
REGENERON

Intellia THERAPEUTICS

Initial Focus
- Liver Diseases (LNP Delivery)

Additional Exploration
- Eye
- Muscle
- CNS

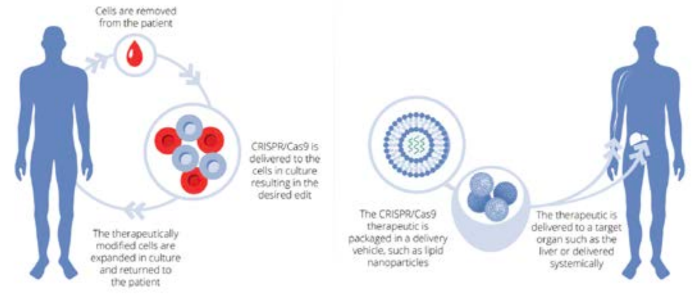
NOVARTIS

Intellia THERAPEUTICS

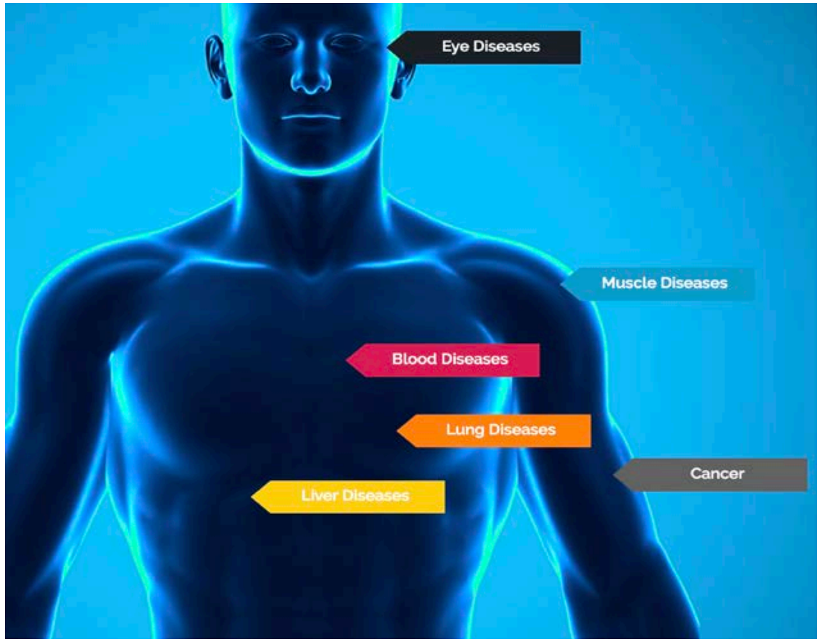
- CAR T oncology
- HSC

- Non-CAR T oncology
- Autoimmune and inflammatory

Program	Editing approach	Research	IND-enabling	Ph I/II	Partner	Structure
Ex vivo: Hematopoietic						
CTX001: β-thalassemia	Disruption			CTA Approved	VERTEX	Collaboration
CTX001: Sickle cell disease (SCD)	Disruption			CTA Approved	VERTEX	Collaboration
Hurler syndrome (MPS-1)	Correction					Wholly-owned
Severe combined immunodeficiency (SCID)	Correction				CASEBIA	Joint venture
Ex vivo: Immuno-oncology						
CTX110: Anti-CD19 allogeneic CAR-T	Various			IND filing YE18		Wholly-owned
CTX120: Anti-BCMA allogeneic CAR-T	Various					Wholly-owned
CTX130: Anti-CD70 allogeneic CAR-T	Various					Wholly-owned
Ex vivo: Regenerative Medicine						
Type I diabetes mellitus	Various				VIACYTE	Collaboration
In vivo: Liver						
Glycogen storage disease Ia (GSD Ia)	Correction					Wholly-owned
Hemophilia	Correction				CASEBIA	Joint venture
In vivo: Other organs						
Duchenne muscular dystrophy (DMD)	Disruption					Wholly-owned
Cystic fibrosis (CF)	Correction				VERTEX	License option



Our Programs	Editing Mechanism	Delivery Mode	Commercial Rights	Discovery
Eye Diseases				
Leber Congenital Amaurosis 10	NHEJ - Small Deletion	AAV local injection	editas	
Genetic and Infectious Disease(s) of Eye *Usher Syndrome 2a, HSV-1*	NHEJ	AAV local injection	editas	
Engineered T Cells				
Gene Editing in T Cells to Treat Cancer	NHEJ	RNP ex vivo	Juno	
Additional Research Programs				
Non-Malignant Hematologic Diseases *Beta Thalassemia, Sickle Cell*	NHEJ & HDR	RNP ex vivo	editas	
Genetic Disease(s) of Muscle *Duchenne Muscular Dystrophy*	NHEJ - Small & Large Deletion	AAV or LNP	editas	
Genetic Disease(s) of Lung *Cystic Fibrosis*	NHEJ & HDR	AAV or LNP	editas	
Genetic and Infectious Disease(s) of Liver *Alpha-1 Antitrypsin Deficiency*	NHEJ & HDR	AAV or LNP	editas	



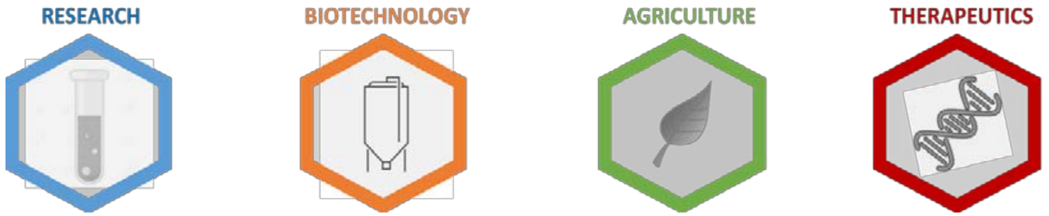
Bacteria

Species	Industrial relevance	Modification(s)	Refs
Bacteria			
Bacillus smithii	Moderate thermophile capable of C_5 and C_6 sugar metabolism	Recombination	[81]
Bacillus subtilis	Producer of industrial enzymes and valuable low-molecular-weight substances	Recombination	[82]
Clostridium autoethanogenum	Capable of fermenting CO, CO_2, and H_2 into biofuel ethanol and 2,3-butanediol	Recombination	[83]
Clostridium beijerinckii	Production strain for biofuels and biochemical	Recombination and CRISPRi	[84,85]
Clostridium cellulolyticum	Capable of conversion of lignocellulosic biomass to valuable endproducts	Recombination	[86]
Corynebacterium glutamicum	Producer of amino acids	CRISPRi	[87]
Clostridium ljungdahlii	Capable of producing ethanol from synthesis gas	Recombination	[88]
Clostridium pasteurianum	Capable of converting waste glycerol to butanol	Recombination	[89]
Escherichia coli	Common production strain	Programmed antimicrobial, recombination, multiplex recombination, CRISPRi, multiplexed CRISPRi, gene circuit, RNA targeting	[5,6,12,26,51,52, 55,71,75,90–94]
Lactobacillus reuteri	Probiotic strain and producer of biotherapeutics	Recombination	[95]
Streptococcus thermophilus	Probiotic and industrial fermentation strains	Engineered immunity	[3]
Streptomyces albus	Producer of heterologous secondary metabolites	Recombination	[96]
Streptomyces coelicolor	Source of pharmacologically active and industrially relevant secondary metabolites	Recombination and CRISPRi	[69,96]
Streptomyces lividans	Source of pharmacologically active and industrially relevant secondary metabolites	Recombination	[96]
Streptomyces viridochromogenes	Source of pharmacologically active and industrially relevant secondary metabolites	Recombination	[96]
Tatumella citrea	Producer of vitamin C precursor (2-keto-D-gluconic acid)	Recombination	[6]
Yeast			
Candida albicans	Common production strain, capable of phenol and formaldehyde catabolism	Recombination and multiplexed recombination	[62,97,98]
Kluyveromyces lactis	Common production strain	Multiplexed recombination	[4]
Pichia pastoris	Common production strain	Multiplex **mutagenesis** and recombination	[99]
Saccharomyces cerevisiae	Common production strain	**Donor-mediated gene disruption**, multiplexed donor-mediated gene disruption, multiplexed recombination, CRISPRa, CRISPRi	[2,7,8,10,40,58, 70,72,100–102]
Ustilago maydis	Natural producer of valuable biochemicals; causative agent of corn smut	Mutagenesis	[103,104]
Yarrowia lipolytica	Natural producer of valuable biochemical	Multiplexed mutagenesis and recombination	[105,106]

Yeast

Fungi

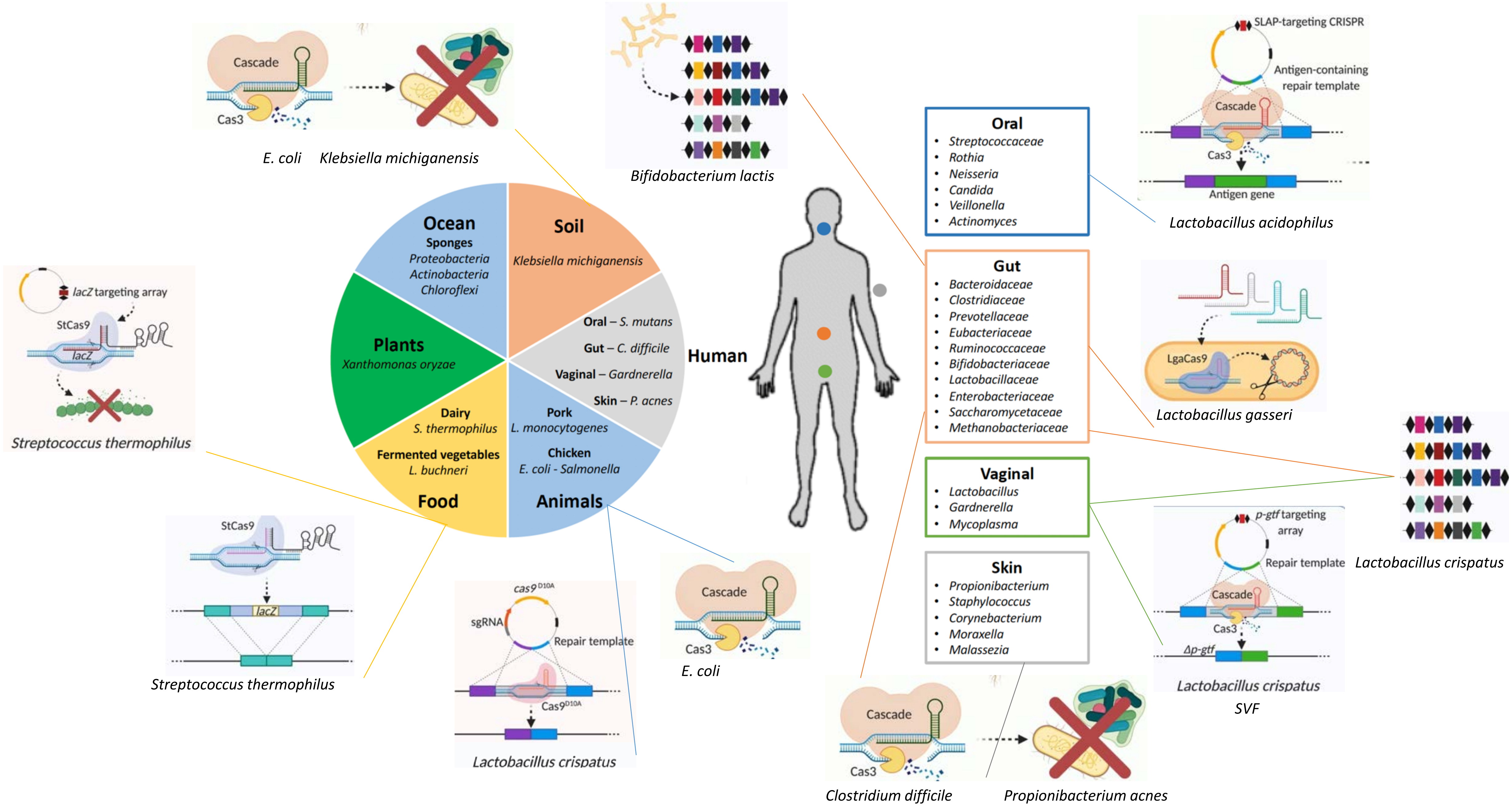
Species	Industrial relevance	Modification(s)	Refs
Filamentous Fungi			
Aspergillus aculeatus	Source of and producer of enzymes	Mutagenesis	[41]
Aspergillus brasiliensis	Source of and producer of enzymes	Mutagenesis	[41]
Aspergillus carbonarius	Source of and producer of enzymes	Mutagenesis	[41]
Aspergillus luchuensis	Source of and producer of enzymes	Mutagenesis	[41]
Aspergillus nidulans	Source of and producer of enzymes	Mutagenesis	[41]
Aspergillus niger	Source of and producer of enzymes	Mutagenesis	[41]
Aspergillus oryzae	Production strain of enzymes and heterologous proteins; also an industrial fermentation strain	Mutagenesis	[107]
Myceliophthora thermophile	Thermophilic strain and producer of cellulases	Mutagenesis, recombination, multiplexed recombination	[108]
Neurospora crassa	Producer of industrially relevant lignocellulosic enzymes	Recombination	[64]
Penicillium chrysogenum	Producer of β-lactam antibiotics	Recombination	[66]
Trichoderma reesei	Common production strain	Mutagenesis and recombination	[59]

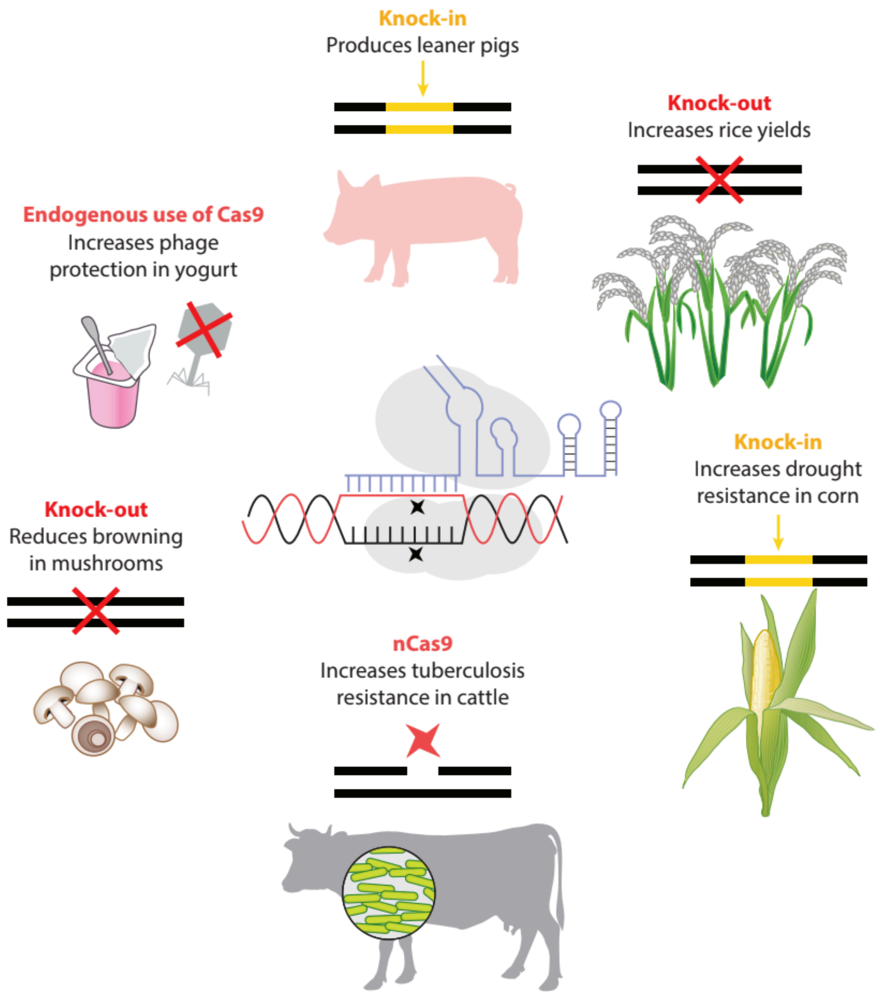


RESEARCH	BIOTECHNOLOGY	AGRICULTURE	THERAPEUTICS
Enzymes Proteins	Enzymes Biofuels Biomass Vitamins	Cheese Yoghurt	Probiotics Antibiotics Insulin

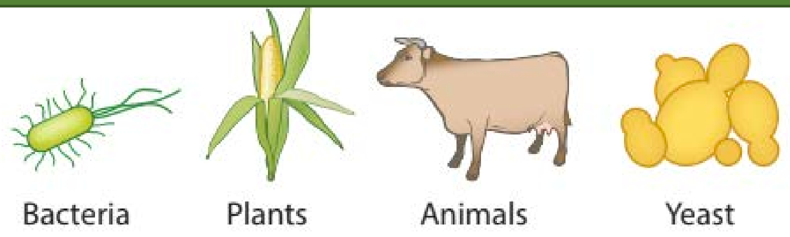
Industrial Biotechnology

Donohoue *et al.* 2017


Cascade
Cas3
E. coli
Klebsiella michiganensis
Bifidobacterium lactis
SLAP-targeting CRISPR
Antigen-containing repair template
Cascade
Cas3
Antigen gene
Lactobacillus acidophilus
Oral
Streptococcaceae
Rothia
Neisseria
Candida
Veillonella
Actinomyces
Gut
Bacteroidaceae
Clostridiaceae
Prevotellaceae
Eubacteriaceae
Ruminococcaceae
Bifidobacteriaceae
Lactobacillaceae
Enterobacteriaceae
Saccharomycetaceae
Methanobacteriaceae
Vaginal
Lactobacillus
Gardnerella
Mycoplasma
Skin
Propionibacterium
Staphylococcus
Corynebacterium
Moraxella
Malassezia
LgaCas9
Lactobacillus gasseri
Lactobacillus crispatus
p-gtf targeting array
Repair template
Cascade
Cas3
Δp-gtf
Lactobacillus crispatus
SVF
Ocean
Sponges
Proteobacteria
Actinobacteria
Chloroflexi
Soil
Klebsiella michiganensis
Plants
Xanthomonas oryzae
Oral – S. mutans
Gut – C. difficile
Vaginal – Gardnerella
Skin – P. acnes
Human
Dairy
S. thermophilus
Pork
L. monocytogenes
Fermented vegetables
L. buchneri
Chicken
E. coli - Salmonella
Food
Animals
lacZ targeting array
StCas9
lacZ
Streptococcus thermophilus
StCas9
lacZ
Streptococcus thermophilus
cas9 D10A
sgRNA
Repair template
Cas9 D10A
Lactobacillus crispatus
Cascade
Cas3
E. coli
Cascade
Cas3
Clostridium difficile
Propionibacterium acnes



Corn Wheat Soy	Crops
Tomatoes Mushrooms	Fruits & vegetables
Tobacco / cotton / hemp Trees Cellulose	Non-food crops Forestry Bio-energy



Ag diversification

Brandt & Barrangou 2019

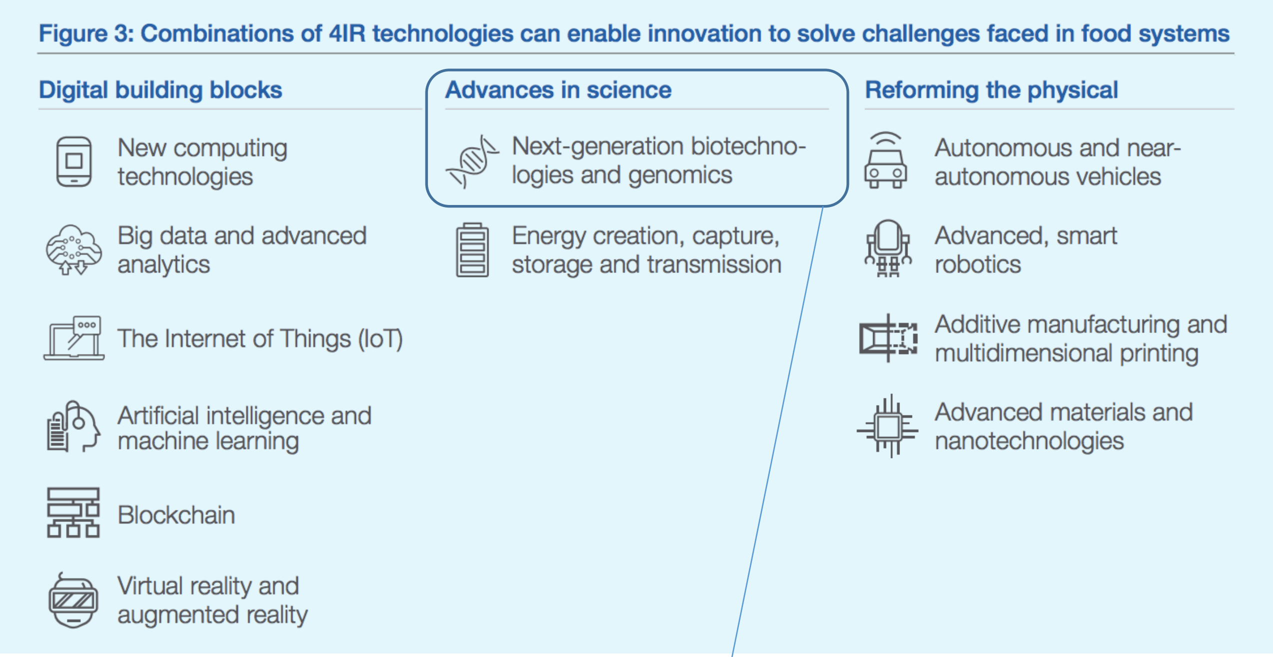
WORLD ECONOMIC FORUM

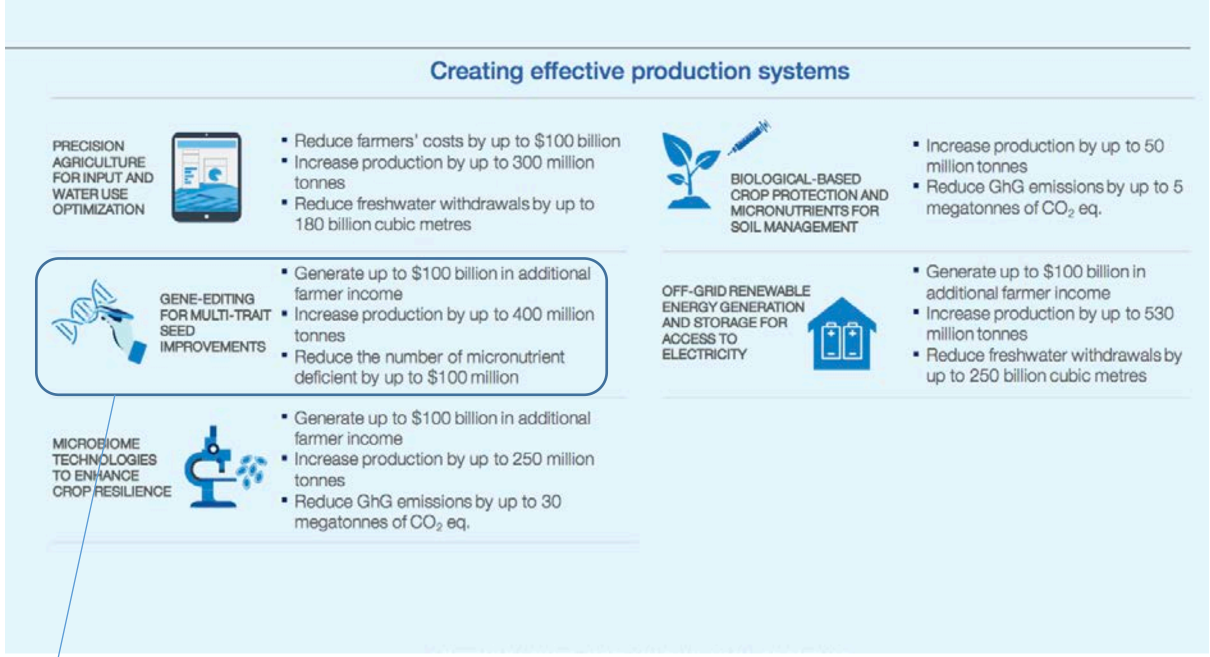
COMMITTED TO IMPROVING THE STATE OF THE WORLD

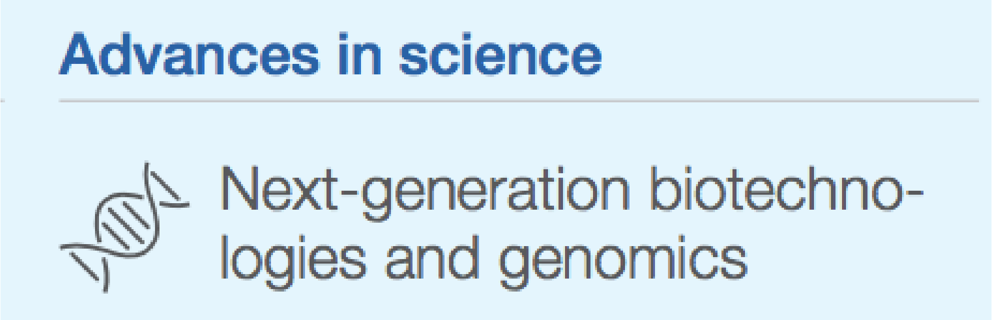
System Initiative on Shaping the Future of Food Security and Agriculture

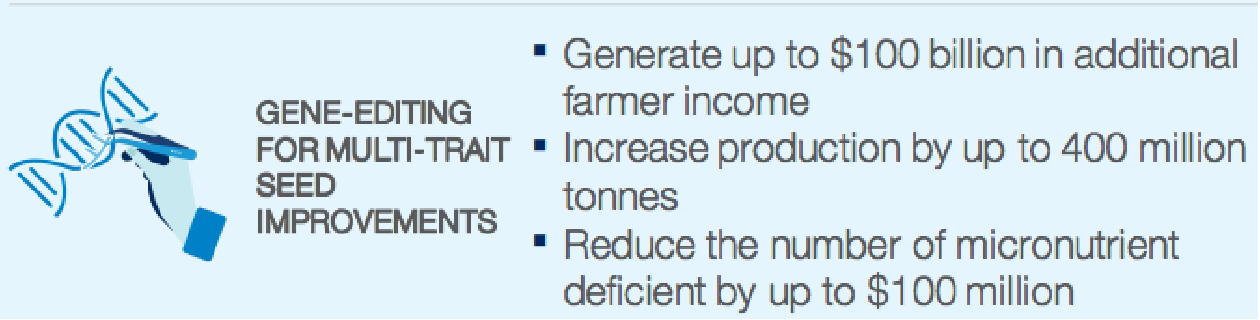
Innovation with a Purpose:
The role of technology innovation in accelerating food systems transformation

CRISPR is a breeding game changer for Ag

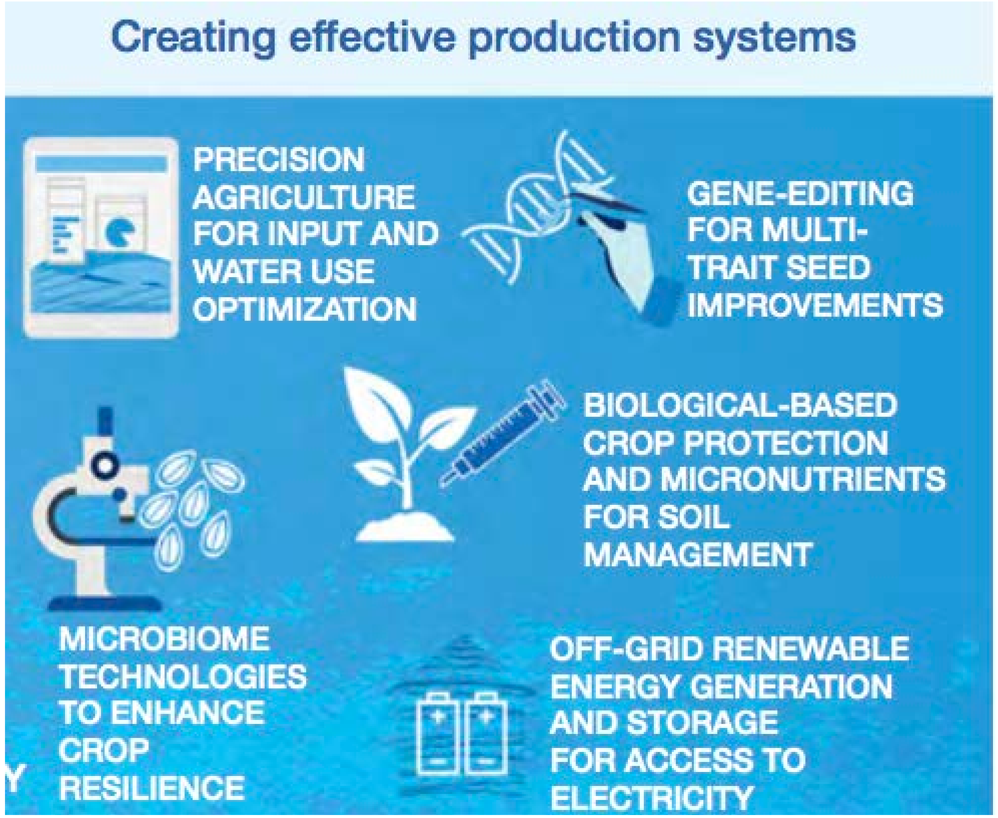








CRISPR is a breeding game changer for Ag



GENE-EDITING FOR MULTI-TRAIT SEED IMPROVEMENTS	**10-15% of farms (60-100 million farms)** chose to use gene-edited seeds by 2030	**Increased income** Billions of dollars	40-100	1-2% of the total agricultural production value[49]	Increased yield, and reduced loss from drought, pest and disease
		Increased yields Millions of tonnes	100-400	1-5% of the total agricultural production[46]	Increased yield from improved seed genotype
		Reduced food loss Millions of tonnes	5-20	1-2% of total food losses[50]	Increased crop resilience to pest, disease and drought
		Reduced micronutrient def. Million people	20-100	1-5% of total people in a state of malnutrition[51]	Ability to biofortify seeds and crops

CRISPR is a breeding game changer for Ag

BBC
WIRED
The Washington Post
Democracy Dies in Darkness
npr
THE NEW YORKER
TIME
REUTERS
The New York Times
MIT Technology Review
HUMAN NATURE

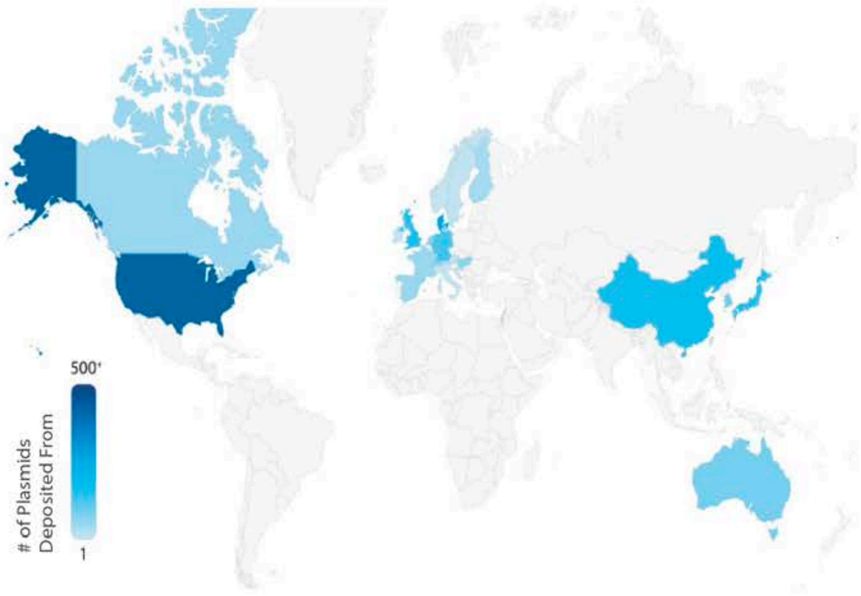
CARIBOU BIOSCIENCES
LOCUS BIOSCIENCES
Intellia THERAPEUTICS
ELIGO BIOSCIENCE
NEXTBIOTICS
editas MEDICINE
SNIPRBIOME
ers GENOMICS
LifeEDIT
TWELVE.BIO
CRISPR THERAPEUTICS
arbor biotechnologies
Beam THERAPEUTICS
CASPR
MammothBiosciences
CASEBIA THERAPEUTICS
CASZYME
SHERLOCK BIOSCIENCES
pairwise
TESSERA
TREECO
egenesis ENGINEERING LIFE
CASTAG BioSciences
GRAPHITE BIO
acrigen BIOSCIENCES
INARI
METAGENOMI
CRISPRBIOTECH

The CRISPR craze: fueling the bio-economy

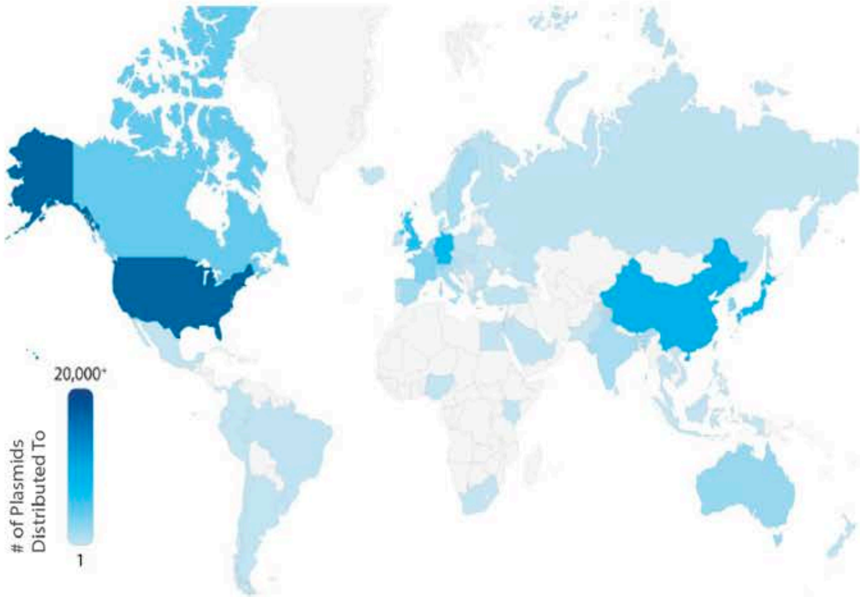
CARIBOU BIOSCIENCES · Intellia THERAPEUTICS · CRISPR THERAPEUTICS · ers GENOMICS · editas MEDICINE · Beam THERAPEUTICS

CASZYME · arbor biotechnologies · LifeEDIT · CasTag BioSciences · acrigen BIOSCIENCES · TWELVE.BIO · CRISPR BIOTECH ENGINEERING · METAGENOMI · CRISPR BIOTECH

Where CRISPR Plasmids Were Deposited From



Where CRISPR Plasmids Were Distributed To



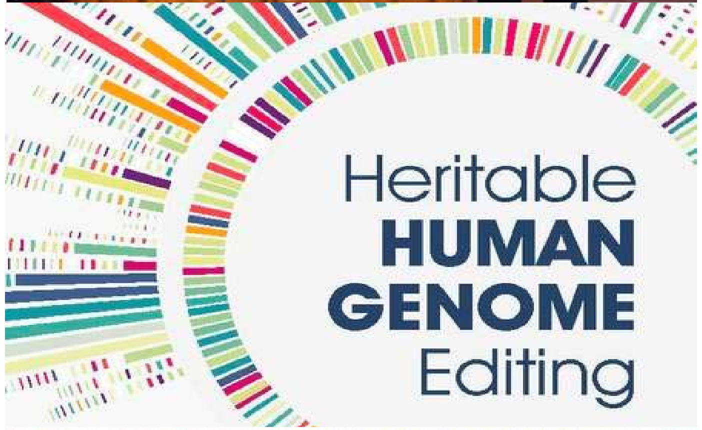
CASEBIA THERAPEUTICS · MammothBiosciences · SHERLOCK BIOSCIENCES · egenesis ENGINEERING LIFE · CASPR BIOTECH · EXCISION · TESSERA · GRAPHITE BIO

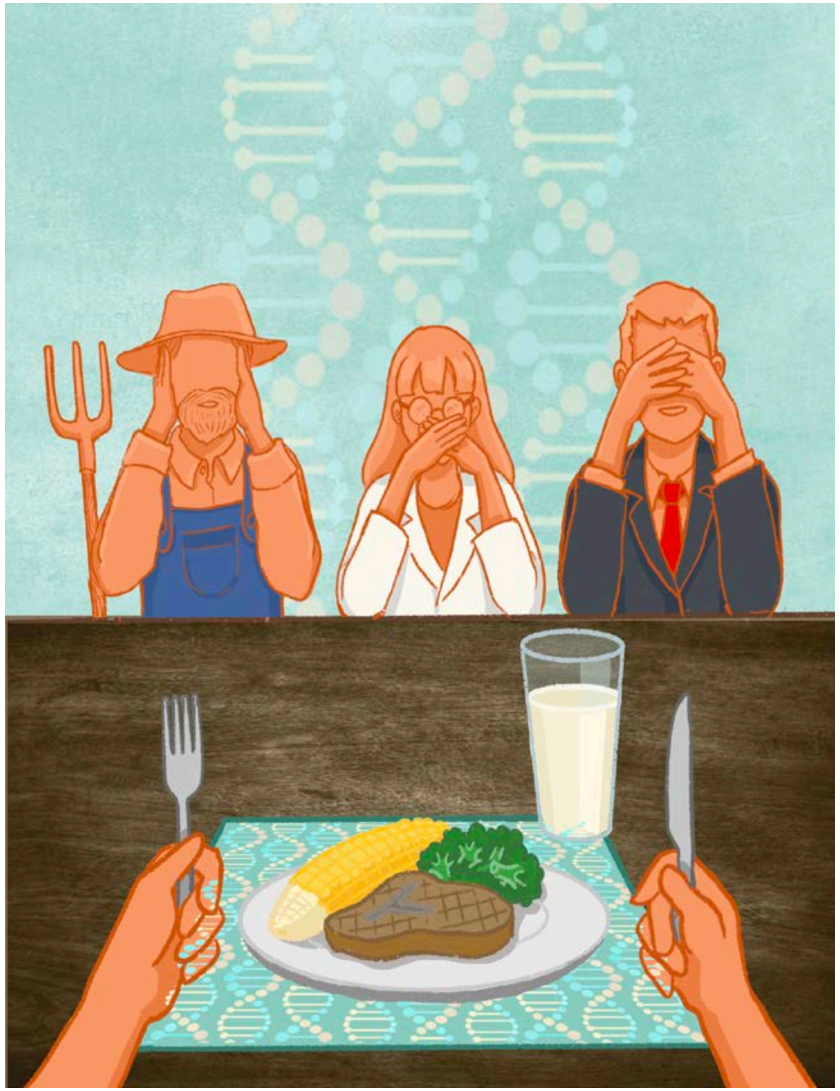
INARI A Flagship Pioneering Company · pairwise · TREECO · LOCUS BIOSCIENCES · NEXTBIOTICS · ELIGO BIOSCIENCE · SNIPRBIOME A CRISPR COMPANY

NASDAQ $10B

Societal implications

- Ethics
  - Editing the human germline
  - Pace and scale and accessibility
  - Dialogue framework and moratorium
- Public relations
  - GMO concerns
  - Oxford debate
  - Voices and stakeholders
- Regulatory Path(s)
  - Medicine vs. Ag
  - Risk:Benefit
  - DNA-free, non-GMO options





Narratives and dialogues

HUMAN NATURE

DAVID BALTIMORE
Cal Tech

JILL BANFIELD
UC Berkeley

RODOLPHE BARRANGOU
NC State University

ALTA CHARO
U of Wisconsin – Madison

EMMANUELLE CHARPENTIER
Max Planck Institute

GEORGE CHURCH
Harvard University

GEORGE DALEY
Harvard Medical School

JENNIFER DOUDNA
UC Berkeley

HANK GREELY
Stanford University

IAN HODDER
Stanford University

STEPHEN HSU
Genomic Prediction

KELSEY MCCLELLAND
DNA Dialogue

FRANCISCO MOJICA
University of Alicante

RYAN PHELAN
Revive and Restore

MATT PORTEUS
Stanford University

ANTONIO REGALADO
MIT Technology Review

DAVID SANCHEZ
Sickle cell patient

SYNTHEGO
RNA synthesis company

FYODOR URNOV
Altius and IGI

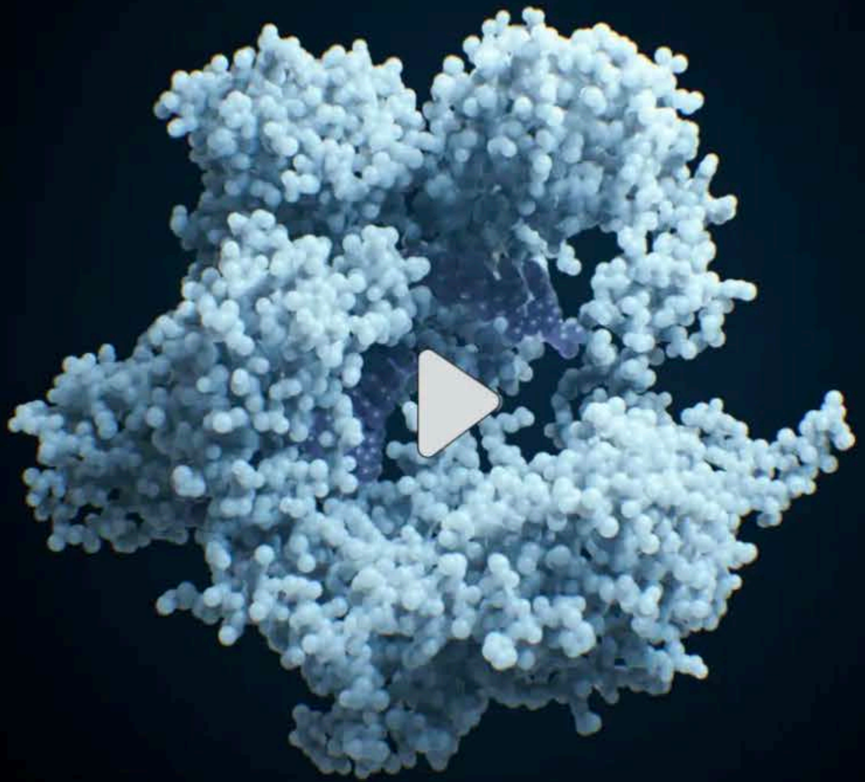
ETHAN WEISS
Ruthie's father

PALMER WEISS
Ruthie's mother

RUTHIE WEISS
5th grader

LUHAN YANG
e-Genesis

FENG ZHANG
Broad Institute



SXSW 2019 FILM FESTIVAL
OFFICIAL SELECTION

OFFICIAL SELECTION
CPH:DOX
2019

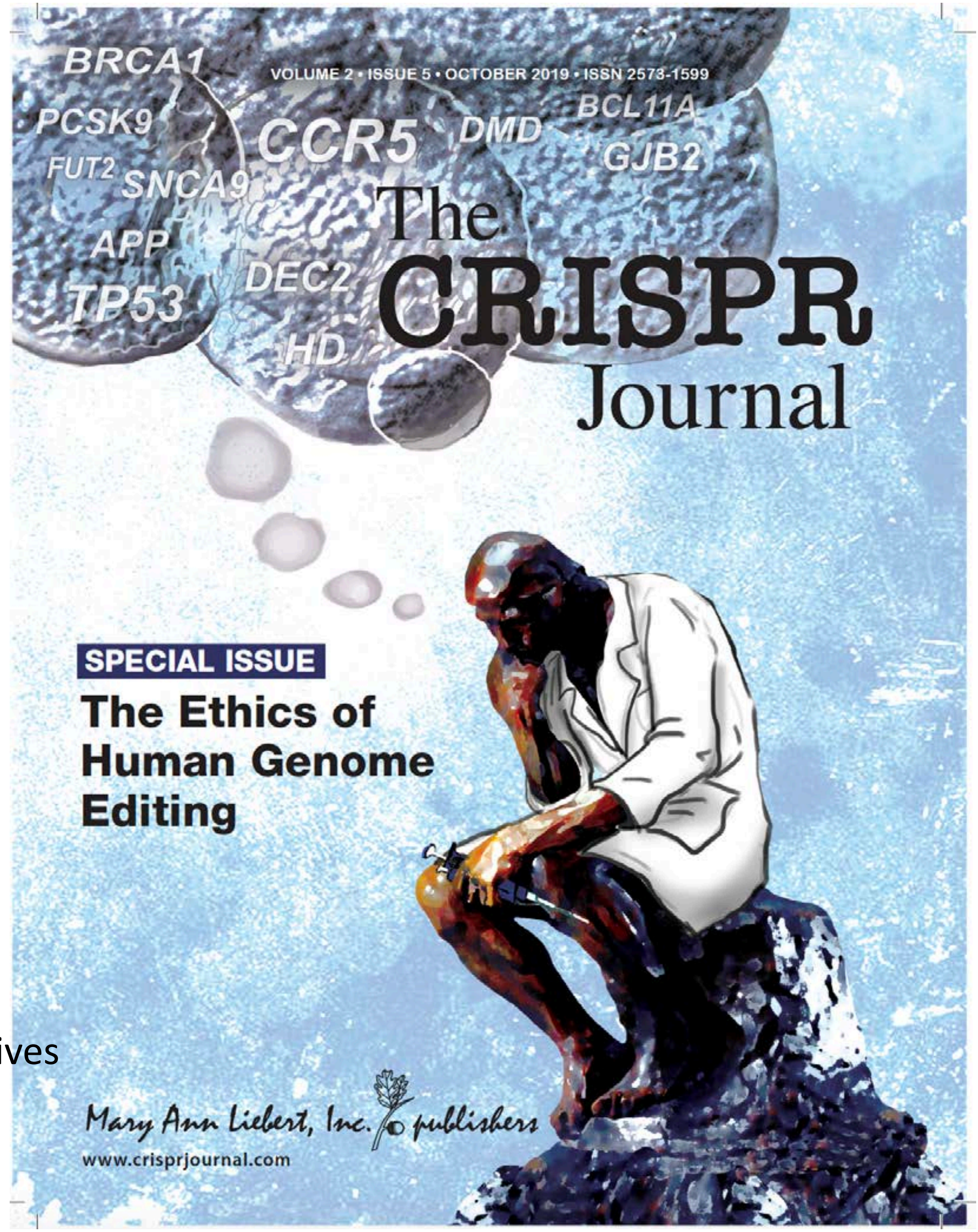
OFFICIAL SELECTION
hotDOCS
2019 OUTSPOKEN.OUTSTANDING.

OFFICIAL SELECTION
full frame
documentary film festival
2019

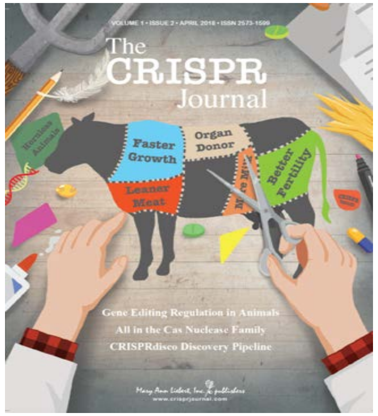
OFFICIAL SELECTION
INTERNATIONAL COMPETITION

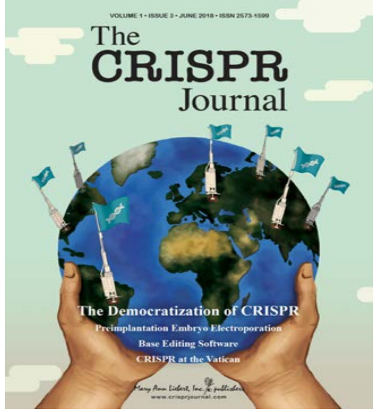
- Greely: ethically defensible, now new, not soon
- Hurlbut: 6 principles for governance*
- McIntosh: the downside of a global moratorium
- Carroll: the daunting economics of gene therapies
- Knoppers: future children rights to health
- Alpern: human rights impact assessment
- Sherkow: regulating through law and legal regimes

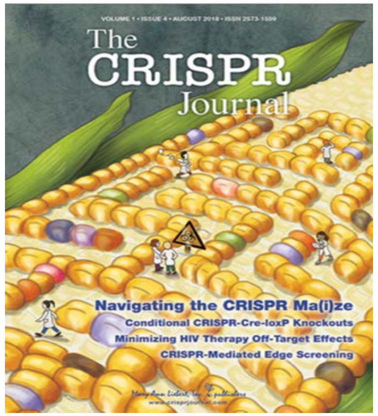
1. Make room for greater diversity in posing and framing questions
2. Ask about the purposes of research before next steps are taken
3. Do not champion self governance by scientists
4. Reflect on the global nature of human values, especially human integrity
5. Rein in the language of “running ahead” to account for broader perspectives
6. Consider researchers’ intentions along with their practices



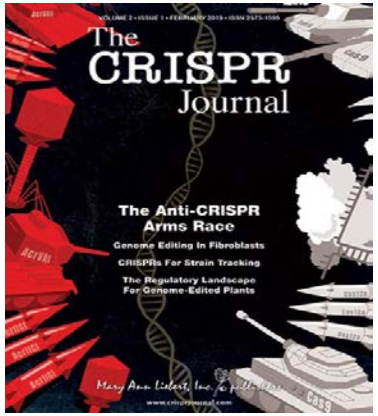

The CRISPR Journal
DEBUT ISSUE 2018
Advances in Gene Editing Technology and Applications
Peer Review, Analysis and Commentary


The CRISPR Journal
Faster Growth
Organ Donor
Better Fertility
Leaner Meat
Gene Editing Regulation in Animals
All in the Cas Nuclease Family
CRISPRdisco Discovery Pipeline

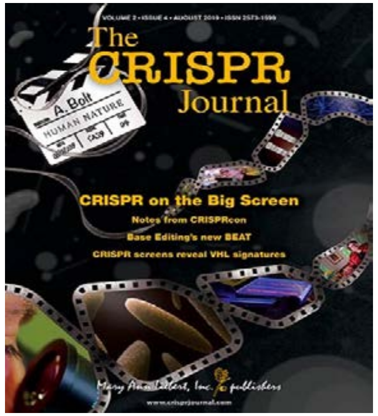

The CRISPR Journal
The Democratization of CRISPR
Preimplantation Embryo Electroporation
Base Editing Software
CRISPR at the Vatican


The CRISPR Journal
Navigating the CRISPR Ma(i)ze
Conditional CRISPR-Cre-loxP Knockouts
Minimizing HIV Therapy Off-Target Effects
CRISPR-Mediated Edge Screening

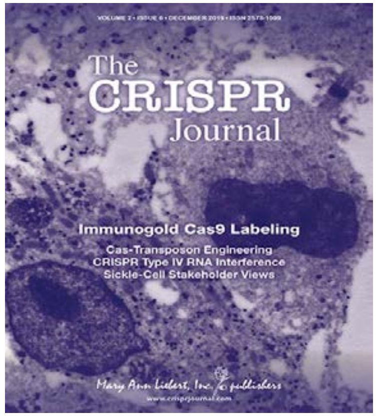

The CRISPR Journal
Special Delivery: CRISPR-Cas9 and gRNA complexes

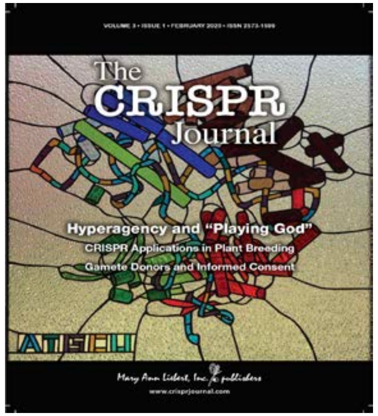

The CRISPR Journal
The Anti-CRISPR Arms Race
Genome Editing In Fibroblasts
CRISPRs Far Strain Tracking
The Regulatory Landscape For Genome-Edited Plants

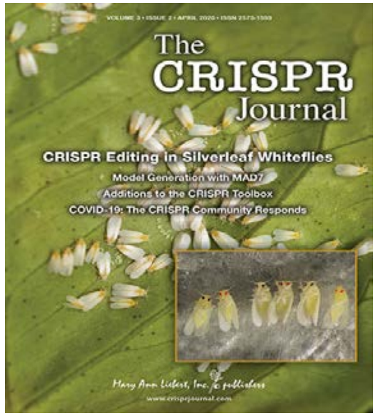

The CRISPR Journal
Plant Genetics: A Study in Emerald
Giving ZFNs the Finger
Pumping up CRISPR pipelines
Regulation of Germline Engineering


The CRISPR Journal
CRISPR on the Big Screen
Notes from CRISPRcon
Base Editing's new BEAT
CRISPR screens reveal VHL signatures


The CRISPR Journal
SPECIAL ISSUE
The Ethics of Human Genome Editing


The CRISPR Journal
Immunogold Cas9 Labeling
Cas-Transposon Engineering
CRISPR Type IV RNA Interference
Sickle-Cell Stakeholder Views


The CRISPR Journal
Hyperagency and "Playing God"
CRISPR Applications in Plant Breeding
Gamete Donors and Informed Consent


The CRISPR Journal
CRISPR Editing in Silverleaf Whiteflies
Model Generation with MAD7
Additions to the CRISPR Toolbox
COVID-19: The CRISPR Community Responds

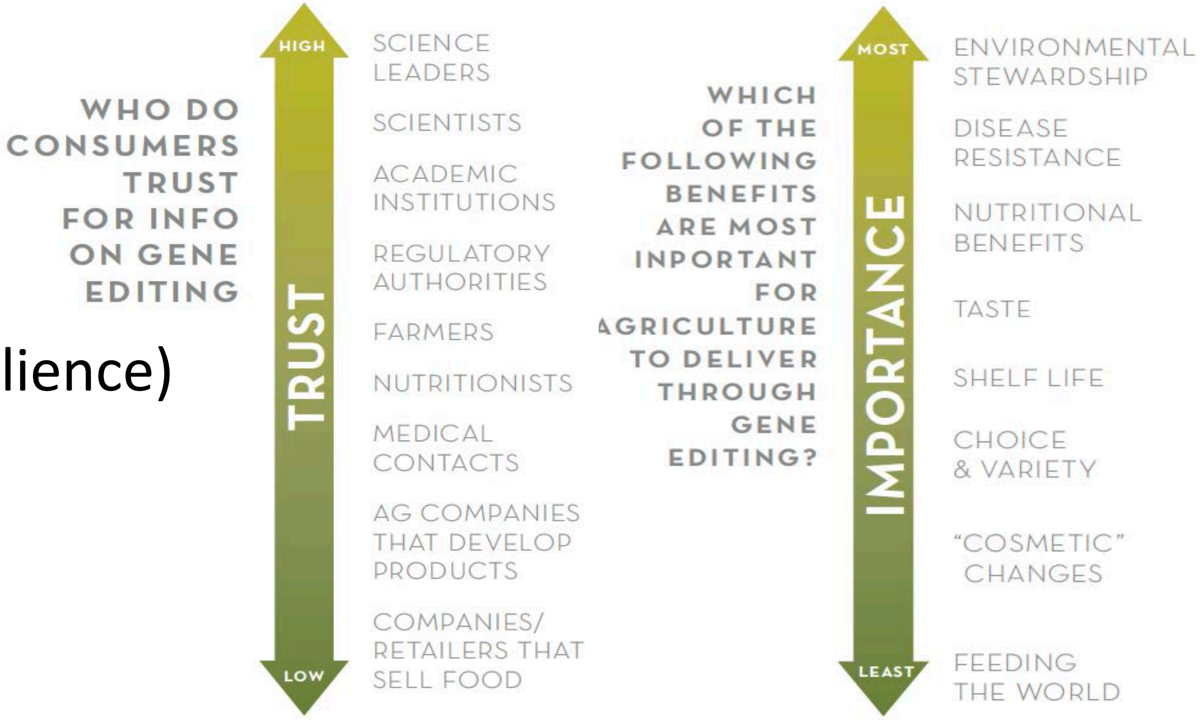

The CRISPR Journal
Endogenous CasRx RNA Targeting
Extreme Diversity of CRISPR-Cas1
Multiplex Genome Editing in T Cells
COVID-19: Testing and Targeting

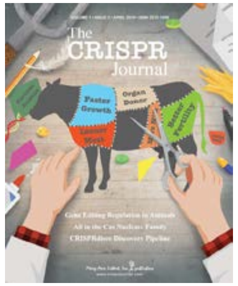

The CRISPR Journal
Translating CRISPR-Cas Therapeutics
AAV Promoters and Cas9 Expression
Type III CRISPR RNA Knockdown in Zebrafish
Editing All Over the World

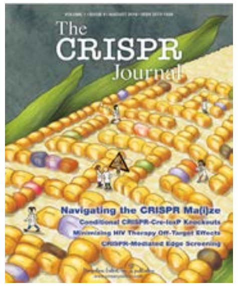
The CRISPR J

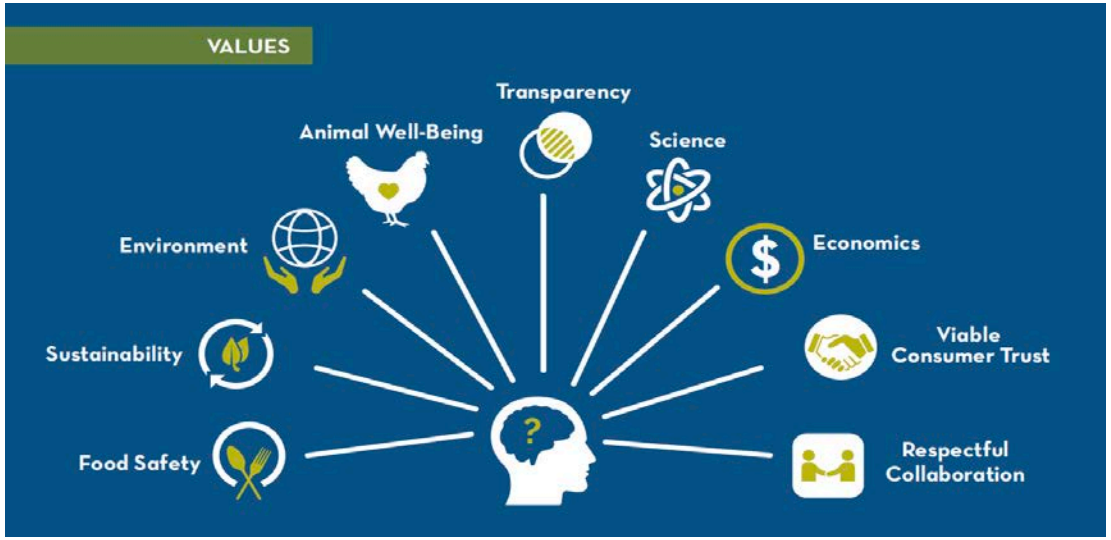
- Values (stewardship, safety, efficacy)
- Trustworthy voices (farmers, scientists)
- Environmental benefits (sustainability, resilience)
- Consumer benefits

GeneEditing.FoodIntegrity.org



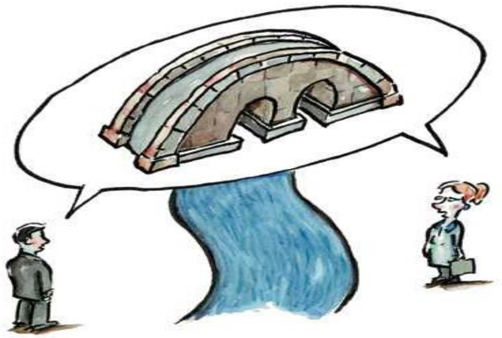


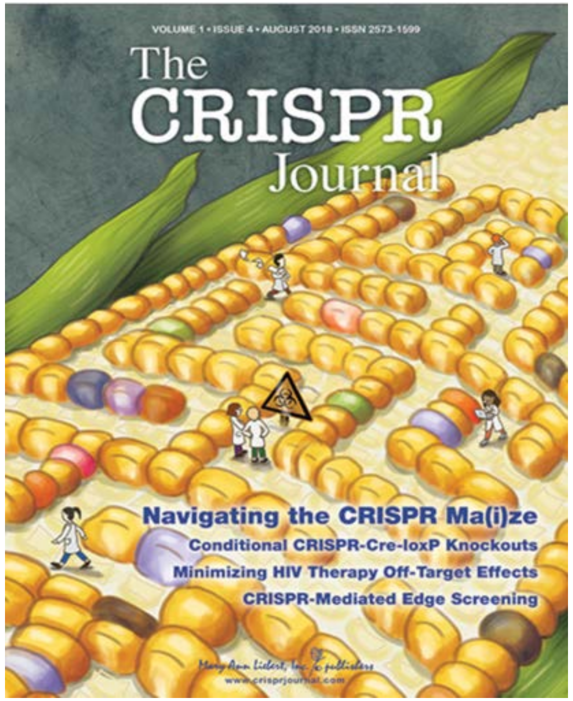




Framing the dialogue

- Ethical issues focused on human germline
- IP wars focused on human therapies; cross licensing pool
- Technical access and implementation feasibility (delivery)
- Recapitulation of natural diverse genotypes
- Early regulatory indications (USDA vs. ECJ, SECURE)
- Use of RNPs and non-foreign DNA implications (DNA-free)
- Non-DNA editing alternatives (CRISPRi|a|e|epi)
- Ability to screen (select phenotype, screen genotype)
- Breadth of applications (foods vs. animals, vs. plants vs. trees)
- Speed of execution, costs, and process timeline
- No concerns about toxicity and immune response

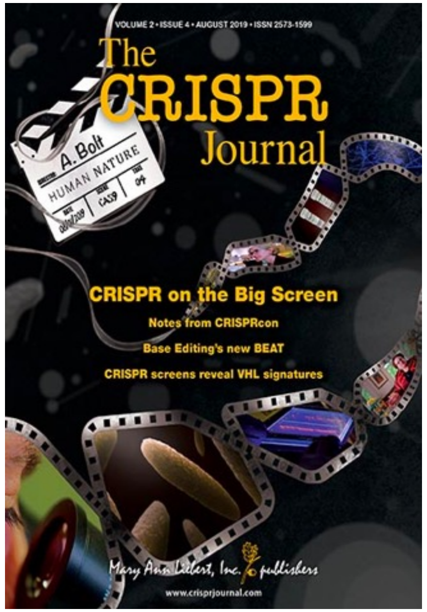


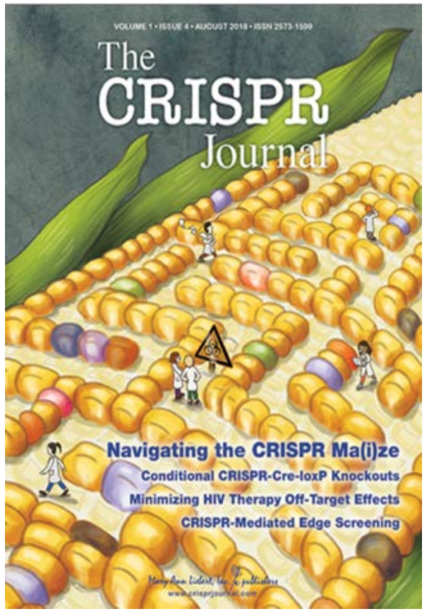


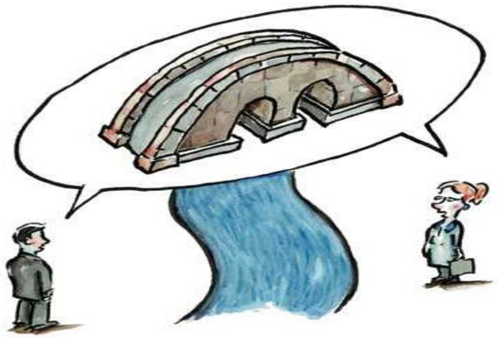
Why Ag is poised to win the CRISPR race

- Clinical success (PR opportunity)
- Public enthusiasm (tech acceptance)
- Europe catches up (rebalancing and shift)
- Put tools to use (industry fuel)
- Beyond Tx (Ag consolidation and diversification)
- Cooler heads prevail (IP and beyond)
- Business deals, M&A
- Responsible guidelines (SECURE rule)
- CRISPR fatigue (tech to products)
- Global geopolitical games (US vs CN)

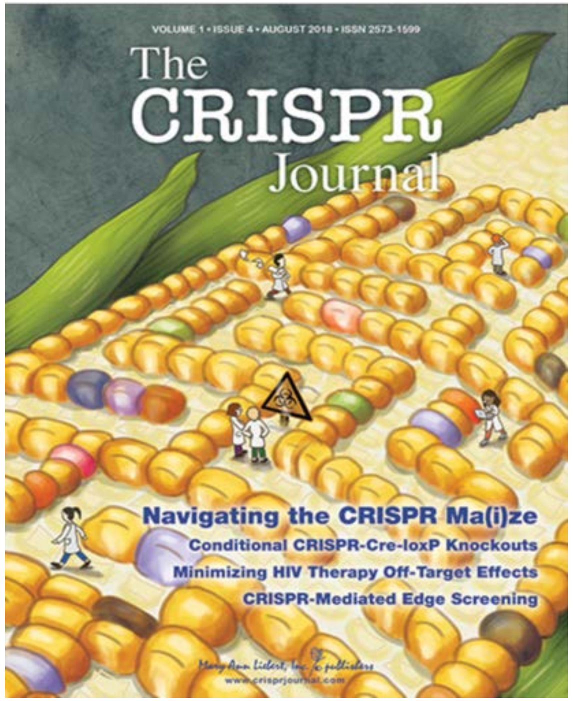
Foresight is 2020:
Ten Bold Predictions for the New CRISPR Year







• Redistribution	USA to EU>USA=CN
• Consolidation	big 6 down to 4
• Communication	re-branding
• Diversification	GM traits vs breeding
	chemicals vs biologicals
	big vs nimble
	dominant vs strategic
	news ventures & partners



The shifting Ag landscape

To Know

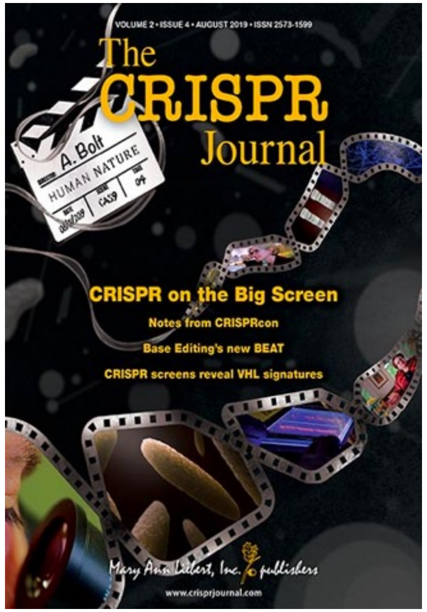
- Beyond Tx
- Disruptive tech
- Democratized
- Tech push & market pull
- 2020 is pivotal

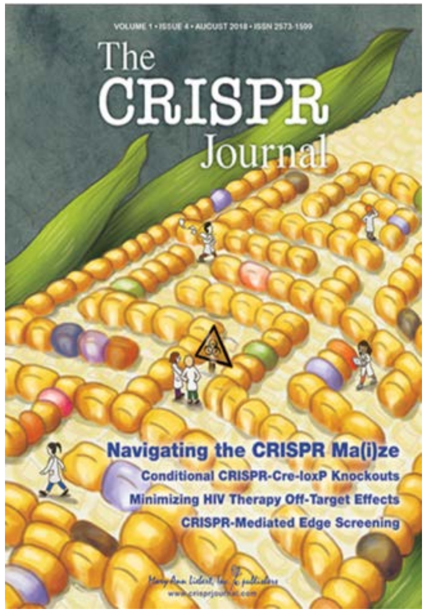
To Ponder

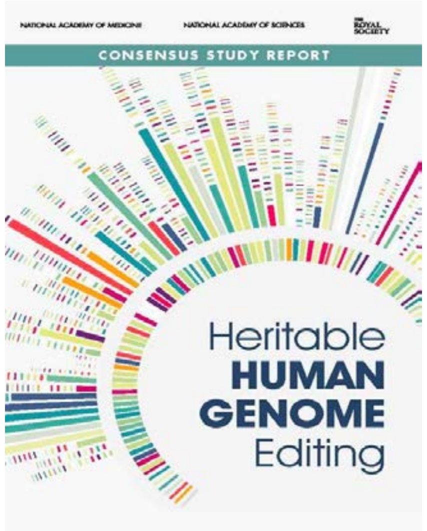
- Acceptance bottleneck
- Tip of the iceberg
- Navigate the nexus
- Science comm. 2.0
- Highway of science

Sci Comm

- Skepticism & Trust
- Transparency & RRI



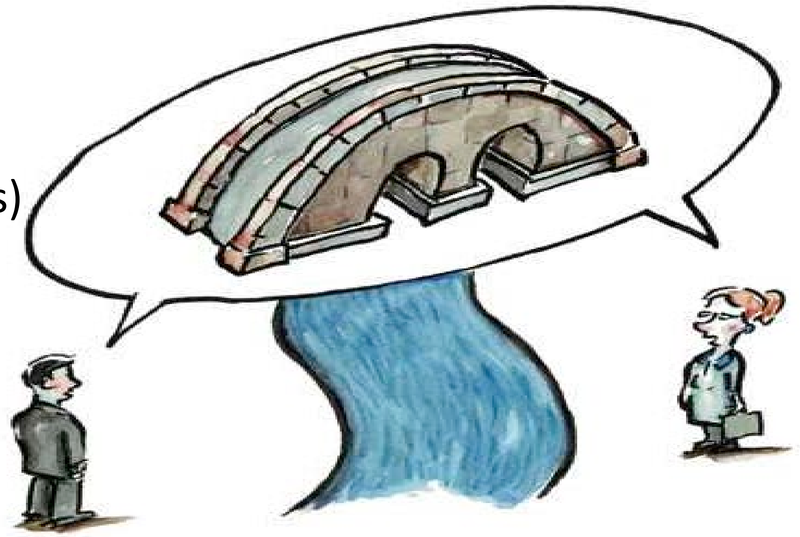




Thinking about CRISPR

Enabling a competitive bio-economy

Government
Politicians
Regulators
Patent office(s)



Academics
Researchers
Universities
Trainees
Thought leaders

Industry
Entrepreneurs
Investors
Partners
Farmers

Society
Public
Consumers
Stakeholders
Media
Ethics (germline)

Science → Technology → Applications → Products

academia — NC STATE — The CRISPR Journal
industry — BASF We create chemistry — TREECO
government — FFAR — FOSTER OUR FUTURE cultivate. discover. grow.
society — SXSW 2019 FILM FESTIVAL — The National Academies of SCIENCES ENGINEERING MEDICINE

The National Academies of SCIENCES ENGINEERING MEDICINE

Researchers

Teachers

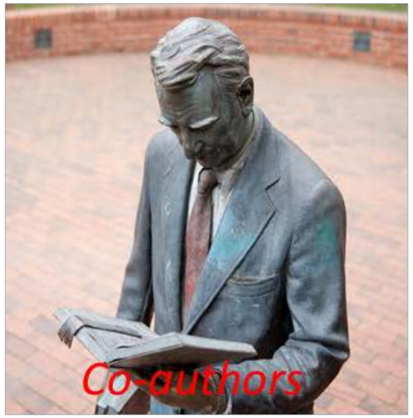
Speakers

Entrepreneurs

Learners

Coaches

Writers



Administrators

Challenging times & inclusive excellence

Funding & collaborations

DUPONT

BASF We create chemistry

Duke UNIVERSITY

North Carolina Biotechnology Center

novozymes Rethink Tomorrow

Berkeley UNIVERSITY OF CALIFORNIA

THERIOT LAB NC STATE

NC Agricultural Foundation, Inc.

Colorado State University

COIs

DUPONT

LOCUS BIOSCIENCES

invaio

TREECO

Intellia THERAPEUTICS

INARI A Flagship Pioneering Company

Ancilia

CARIBOU BIOSCIENCES

The CRISPR Journal

CRISPR BIOTECH