Recombinant biotechnology for enhancing climate adaptation and productivity in forest trees

Essential biological and governance innovations

Presented at International Society for Biosafety Research Congress – May 2023

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How can we start to heal a death caused by a thousand cuts?

Or at least a serious malady caused by a half-dozen big bruises!

Agenda

- Definitions and overview
- The social thicket
- Gene flow as a bioethical dilemma
- Transformation/editing recalcitrance
- Climate change/pest urgency
- Innovations proposed

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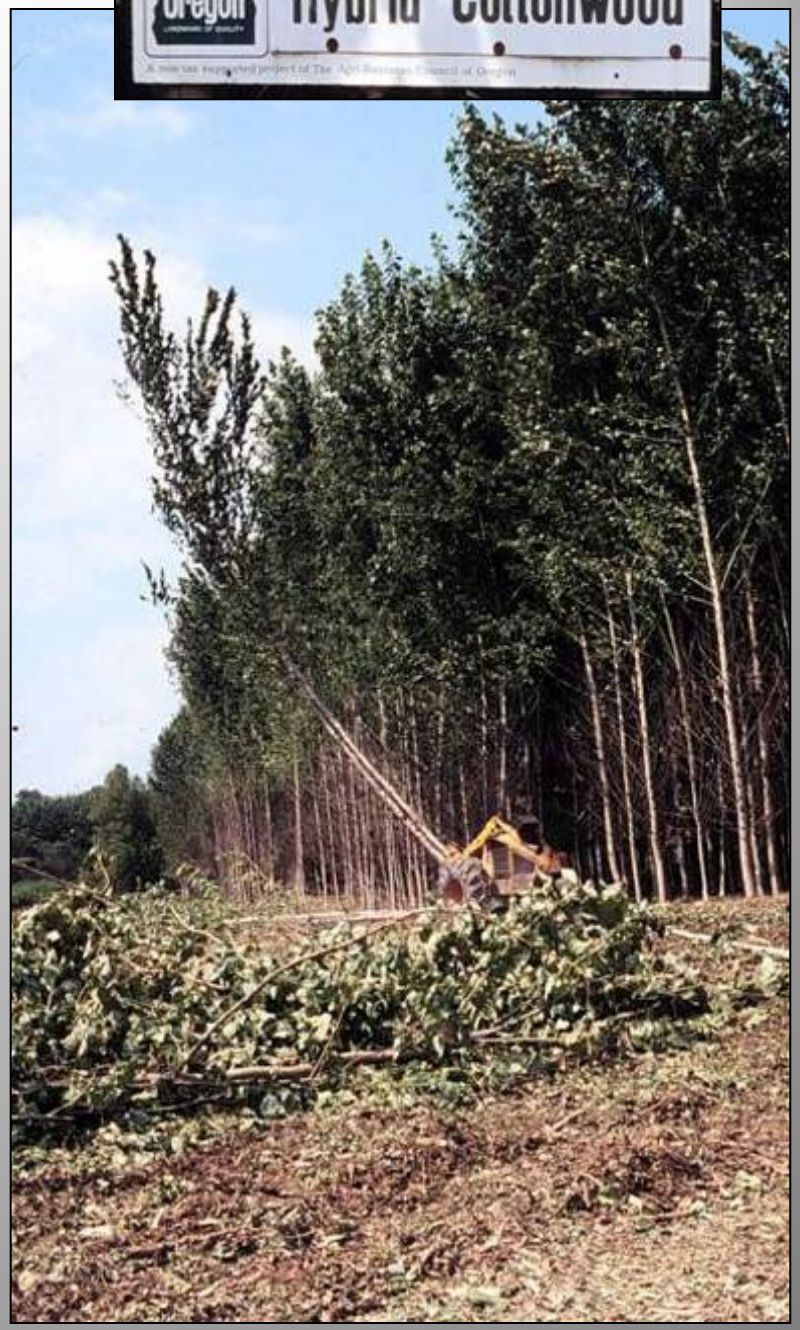
Poplar plantations are examples of my research ecosystem



Eucalypts in Brazil another example of the relevant ecosystem for this talk

Super productive due to conventional breeding – exotics, clones, hybrids, continued cycles of infusion and testing

Forests and sustainable intensification

Most plantations with a mix of production and reserve areas

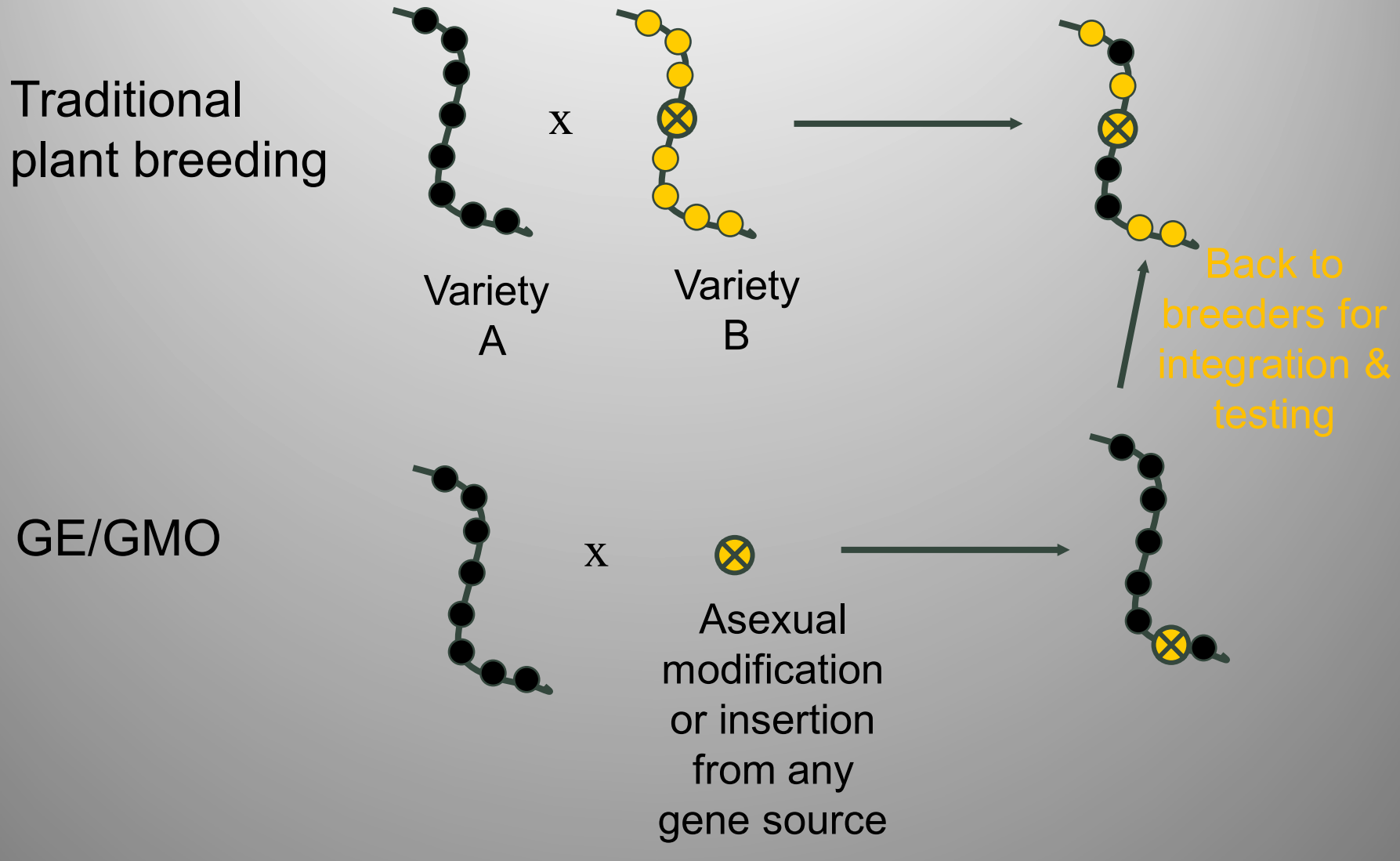
Plantation forests occupy 5% of all forests and deliver 35% of industrial roundwood, usually with diversity preserves

More yield = less potential impact on wild/conservation forests

Biotech for wild forest trees?

American chestnut and many other wild forest species under threat worldwide

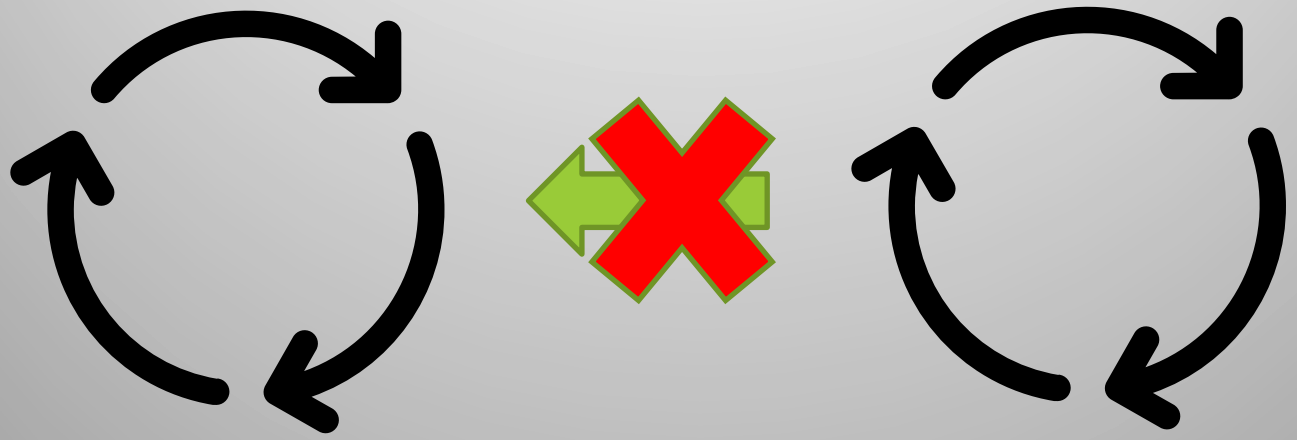
Gene edit/GMO (GE) = “biotech” for the purpose of this talk – not genomic breeding



Relationship of breeding and biotech

Breeding populations

Biotech innovations

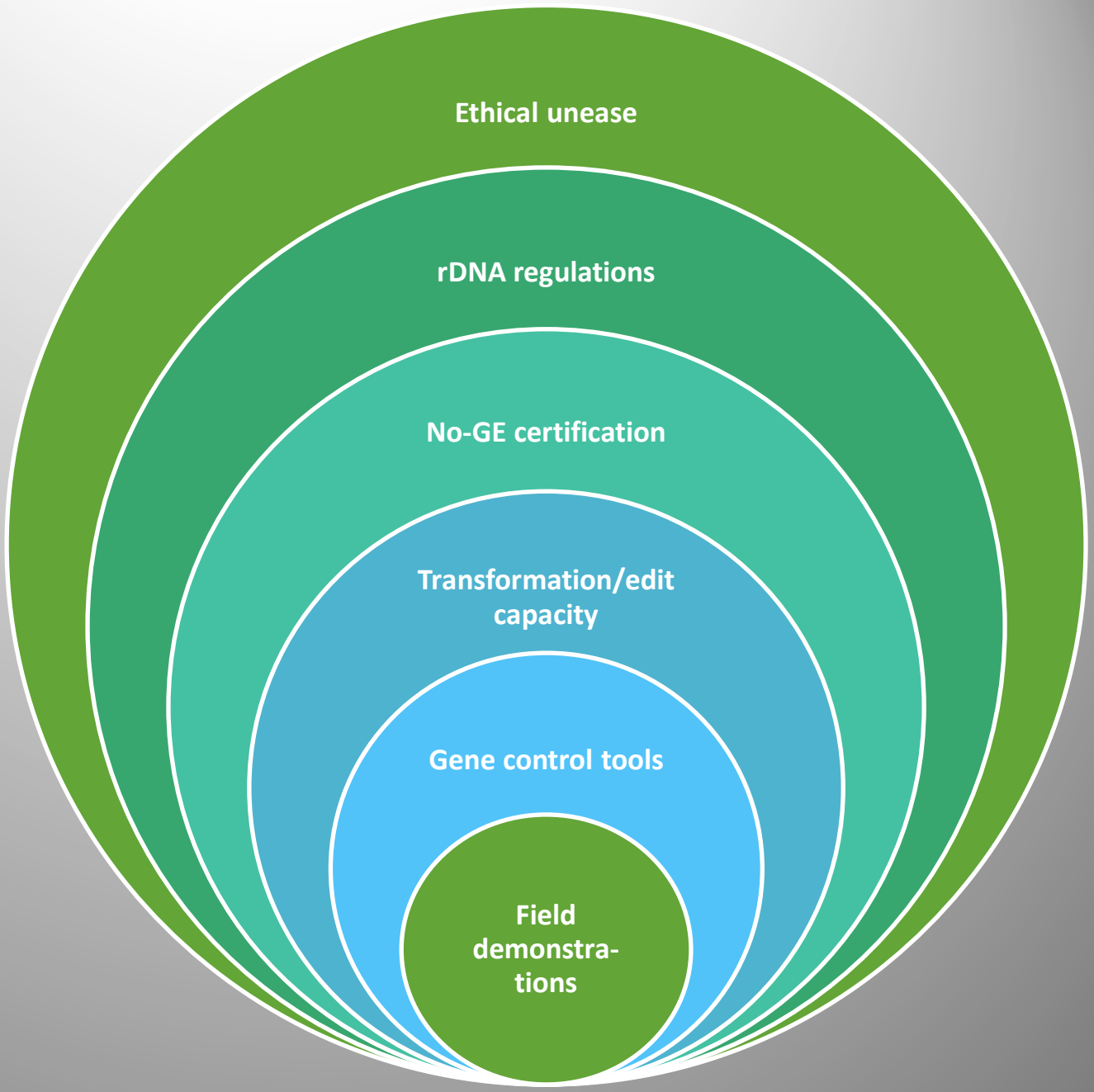


Polygenic:
Growth rate and adaptation

Oligogenic:
Specific modifications and novel traits

These need to be integrated in a way that does not slow down conventional breeding, with its growing power and urgency in a climate changed world

Why is forest biotech under-performing?
It's a nexus of problems constraining progress



Nexus of problems, explained

- **Ethical unease:** Corporations, patents, transparency, plantation monocultures, GMOitis, gene flow
- **rDNA regulations:** rDNA-based presumption of guilt and impairment of effective research and integration with breeding
- **No-GE certification:** Prevention of significant use in research, breeding, or products on certified lands
- **Transformation/edit capacity**: Inability to effectively address a diversity of species and genotypes in breeding programs in reliable, cost-effective manner
- **Gene control tools:** Reliable systems for control of gene expression, excision, editing, and stability when in routine use or for synthetic biology innovations
- **Field demonstrations:** Public evidence that biotech modifications add significant value and do not compromise sustainability, or breeding progress & productivity, in field environments

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The social thicket: Regulations

- Assumes the method used, vs. trait novelty and importance, is a suitable trigger for regulatory oversight
- Effectively treats a GMO insertion, or anything but the simplest gene edit, as guilty until proven innocent through extensive study
- Scientific reports, such as many from the USA National Academy of Sciences, have continually called for a trait/novelty based regulatory system, vs. one based on method

My early attempt to help guide the creation of a trait- based system

POLICY FORUM

GENETIC TECHNOLOGIES

Genomics, Genetic Engineering, and Domestication of Crops

Steven H. Strauss

Genomic sequencing projects are rapidly revealing the content and organization of crop genomes (*1*). By isolating a gene from its background and deliberately modifying its expression, genetic engineering allows the impacts of all genes on their biochemical networks and organismal phenotypes to be discerned, regardless of their level of natural polymorphism. This greatly increases the ability to determine gene function and, thus, to identify new important to agricultural goals, but poorly represented in breeding populations because they are rare or deleterious to wild progenitors, can be created and inserted into varied kinds of germplasm. Traits that have already been genetically engineered in this manner include diverse modifications to plant reproduction, stature, and lipid and lignocellulose chemistry. The improvements achieved via GGTs should be comparable to or of greater value than those obtained via huge numerical obstacle that is normally provided by extant wild and domesticated gene pools. Despite the great diversity of genes that can comprise GGTs, many of the modified traits are familiar, having a long history of domestication and consequent reduced fitness through artificial selection. Male sterility, seedless fruits, delayed spoilage, and dwarf stature are familiar examples.

GGTs that improve abiotic stress tolerance of crops, including tolerance of cold, heat, salt, and drought, would appear to pose a higher risk of spread in the environment than domestication traits. However, physiological considerations and breeding experience suggest this might not be the case. Alterations of regulatory genes that control pathways related to tolerance of abiotic stresses often have

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finement; use of spatial isolation within and between farms and border crops, combined with postharvest monitoring. Detailed data include surveys of gene flow away from the site. Basic data documents establishment of confinement mechanisms.

International forest biotech scientists, after meeting in Oxford in 1999, speak out about the need for field trials

COMMENTARY

GENETICALLY MODIFIED ORGANISMS

Forest biotechnology makes its position known

Steven Strauss, Wout Boerjan, John Cairney, Malcolm Campbell, Jeffrey Dean, David Ellis, Lise Jouanin, and Björn Sundberg

Last July, the world's largest group of scientists studying molecular biology and biotechnology of forest trees met at the University of Oxford, England*. To the surprise of the attendees, the meeting, organized by the International Union of Forestry Research Organizations (IUFRO, Vienna, Austria), was the subject of a protest by an antibiotechnology group called GEFF (Genetic Engineering Free Forests, London, UK). During the meeting, GEFF staged a protest outside the meeting hall (the venerthe environment was an important rationale for the study. Its ultimate goal was to produce trees that require the use of fewer chemicals in paper and pulp production, and thus creating less environmental pollution.

During the session on the deployment of GM trees, and at the business meeting, IUFRO scientists debated a draft position statement on the benefits and risks of GM crops and plantations. Based on comments from the group, the statement was revised and put to a vote via the Internet. It was ratified by 99% of those who

quences or it can produce substantially modified organisms. The large-scale use of transgenic crops in some countries show that transgenic traits can be highly stable after normal field screening of genotypes during breeding. The credible issues center on which genes can be effectively used to modify which traits for which environments.

While transgenic traits pose some risks for plantations and associated ecosystems, many options exist to mitigate their impacts. Priority

At the same time ecovandals destroy the only GE tree field trial in the UK

Tree Biotechnology Conference at Oxford in 1999 - Vandalism against lignin modified trees to “welcome” conferees, Euro-press attacks

FRANKENSTEIN'S FOREST

The tree-top protesters, who confounded the Government's road-building programme by camping in the path of bulldozers, are now poised to target the very trees they might once have called home.

Whilst public attention has been focused on the threat of 'Frankenstein Foods', the same corporations who are forcing us to ingest genetically modified (GM) meals have been quietly perpetrating yet another crime against the environment.

The biotech industry has been understandably tight-lipped about its latest phase of the genetic revolution. But it is currently preparing to take over the world's forests – at what's

ment. Campaigners fear that GM trees will suck up water, nutrients and light, leaving indigenous trees to die out along with the host of insects, plants and fungi which rely upon them. In turn, birds and animals would lose many of their natural prey. Those surviving creatures would fall victim to herbicide weed-killer, liberally applied once the GM trees become resistant. The result, opponents fear, will be a sanitised, silent forest, cleansed of natural life.

This month, activists are targetting the Forest Biotechnology '99 conference, hosted by Oxford Forestry Institute from July 31 - 16. It will bring together some of the world's top

1997. The trees engineered by the University of Derby, to be disease- and insect-resistant, were destroyed by removing the bark. Agreeing spate of raids on food crops caused AstraZeneca to make a statement to the press before a GeneiX Snowball action earlier this year, forcing damage to their GM poplars.

In April, Monsanto teamed up with two of the world's biggest forest and paper corporations, International Paper and Weyerhaeuser. They also got New Zealand company, Fletcher Challenge, in on the deal as they own the all-important patents on newly developed genes which will give the consortium the monopoly on GM trees that they're after. Having sunk

vention, which governs global emissions of greenhouse gases, came into force after the 1997 Kyoto conference, industrialised countries have been forced to clean up. However, the corporations argue that by planting more trees, they should be awarded 'carbon credits', because trees absorb carbon dioxide.

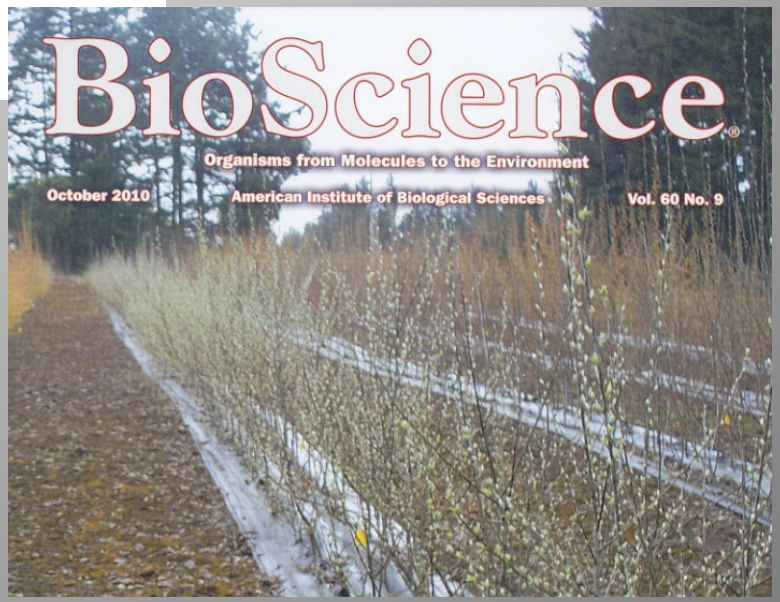
Recently, naturally rich native forests have fallen to the chainsaw, only to be replaced by invasive foreign plantation species such as eucalyptus. To the undiscerning eye, one forest is indistinguishable from another, allowing corporations to hoist about how well they are managing their operations. Look behind the greenwash and companies such as Shell are

Field research continued in USA, but at a very low level – in large part due to risks and effort required for regulatory compliance

Far-reaching Deleterious Impacts of Regulations on Research and Environmental Studies of Recombinant DNA-modified Perennial Biofuel Crops in the United States

STEVEN H. STRAUSS, DREW L. KERSHEN, JOE H. BOUTON, THOMAS P. REDICK, HUIMIN TAN, AND ROGER A. SEDJO

Makes the incremental, trial and error, **adaptive research** that is the norm in forestry nearly impossible as each event or construct class requires regulatory review and decisions before any release to environment is allowed – a critical obstacle to the physiological "tinkering" needed for key traits like drought, heat, and cold tolerance—or wood engineering



Cold tolerant, male-sterile GE *Eucalyptus* saga underlines importance of field-based development

Results from first winter in South Carolina

Control

Lead Line

Images provided by Arborgen

Results from second winter in Alabama

Lead Lines + Control

But technology seemed to fail in subsequent years. Sadly there was no further "tweaking" undertaken to improve the trait – in part due to costly task of regulated field trial management and approvals, and of getting even a single insertion event approved.

The ~new 2020 USDA SECURE system is more enlightened – but improvement may be small?

USDA U.S. DEPARTMENT OF AGRICULTURE

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USDA › MEDIA › PRESS RELEASES › USDA SECURE RULE PAVES WAY FOR AGRICULTURAL INNOVATION

USDA SECURE Rule Paves Way for Agricultural Innovation

(Washington, D.C., May 14, 2020) U.S. Secretary of Agriculture Sonny Perdue today announced a final rule updating and modernizing the U.S. Department of Agriculture's (USDA) biotechnology regulations under the Plant Protection Act. The Sustainable, Ecological, Consistent, Uniform, Responsible, Efficient (SECURE) rule will bring USDA's plant biotechnology regulations into the 21st century by removing duplicative and antiquated processes in order to facilitate

Press Release
Release No. 0260.20

Contact: USDA Press
Email: press@oc.usda.gov

What is a plausible pathway to becoming a plant pest risk?

The social thicket: Market certification

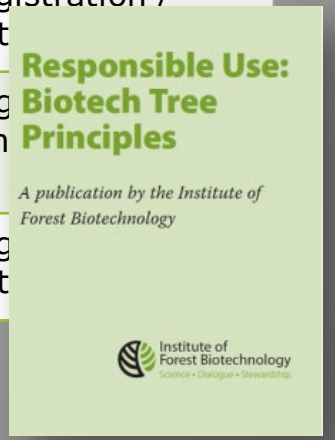
<u>A big deal</u>:
Many of the most highly managed forests and their products are certified

~500 million hectares,
~13% global forest area

Started by the Forest Stewardship Council, major principle:
"genetically modified trees are prohibited"

All major forest certification systems banned GE trees over time

System	Region	GM Tree Approach / Reason
PEFC : Programme for Endorsement of Forest Certification	International	**Banned** / Precautionary approach based on lack of data
FSC : Forest Stewardship Council	International	**Banned** / Precautionary approach based on lack of data
CerFlor : Certificação Florestal	Brazil	**Banned** via PEFC registration / No additional rationale
CertFor : Certficación Forestal	Chile	**Banned** via PEFC registration / No additional rationale
SFI : Sustainable Forestry Initiative	North America	**Banned** via PEFC registration / Awaiting risk-benefit data
ATFS : American Tree Farm System	USA	**Banned** via PEFC registration / No additional rat
CSA : Canadian Standards Association	Canada	**Banned** via PEFC reg Allows public to determ
CFCC : China Forest Certification Council	China	**Banned** via PEFC reg No additional rat



Adam Costanza, Institute for Forest Biotechnology

In 2001 forest genetic and biotech scientists publicly criticized FSC for their complete ban on GMOs – because it does not allow relevant breeding research with them on certified lands

FSC-POL-01-004 (V2-0) POLICY FOR THE ASSOCIATION OF ORGANIZATIONS
FSC

Code	INT-POL-01-004_01
Requirement (s)	Clause 1.e
Publication date	11 July 2011

Does research on GMOs by FSC certificate holders or affiliated organizations constitute a breach of the FSC Policy on Association?

The FSC Policy on Association had its origins in the FSC Partial Certification Policy and is intended to prevent green washing by companies that are not committed to FSC certification. The Policy states that FSC shall not be associated with organizations that are

Helped motivate FSC to create a very narrow research exemption in 2011

In 2015, as evidence of growing pest epidemics and climate stress mounted, we pressed the issue further in another policy essay

Traces of the emerald ash borer on the trunk of a dead ash tree in Michigan, USA. This non-native invasive insect from Asia threatens to kill most North American ash trees.

BIOTECHNOLOGY

Genetically engineered trees: Paralysis from good intentions

Forest crises demand regulation and certification reform

By **Steven H. Strauss[1]*, Adam Costanza[2], Armand Séguin[3]**

Intensive genetic modification is a long-standing practice in agriculture, and, for some species, in woody plant horticulture and forestry (*1*). Current regulatory systems for genetically engineered

recently initiated an update of the Coordinated Framework for the Regulation of Biotechnology (*2*), now is an opportune time to consider foundational changes.

Difficulties of conventional tree breeding make genetic engineering (GE) methods relatively more advantageous for forest trees than for annual crops (*3*). Obstacles

Although only a few forest tree species might be subject to GE in the foreseeable future, regulatory and market obstacles prevent most of these from even being subjects of translational laboratory research. There is also little commercial activity: Only two types of pest-resistant poplars are authorized for commercial use in small areas in China and two types of eucalypts, one approved in Brazil and another under lengthy review in the USA (*5*).

METHOD-FOCUSED AND MISGUIDED. Many high-level science reports state that the GE method is no more risky than conventional breeding, but regulations around the world essentially presume that GE is hazardous and requires strict containment

…also with little effect

Petition created about GMO/gene edit ban by certification programs – implemented by Alliance for Science at Cornell University, USA

Endorsed by the largest scientific society of plant biologists in the world

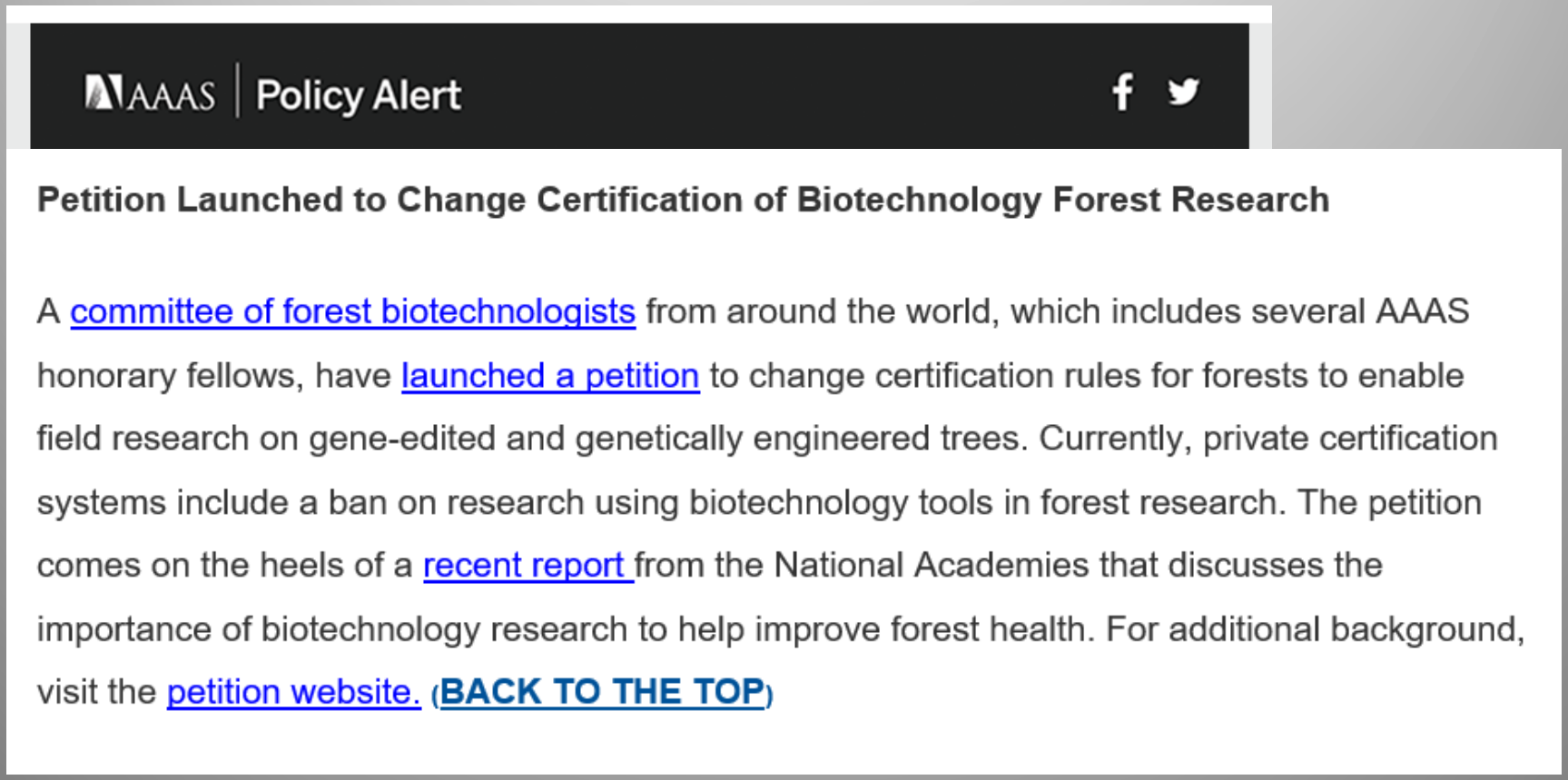
American Society of Plant Biologists

ASPB has studied and endorsed the petition.

members to support a petition to change certification rules for forests to enable field research on biotech (gene edited, genetically engineered) trees. Amazingly, all of the private certification systems have a complete ban in place that extends to research, at a time when forest health is in growing crisis due to expanding pests and climate change. Biotech is not a panacea, but its also too powerful to ignore—and can sometimes provide powerful solutions where other approaches fail.The petition follows the release of a major report on The Potential for Biotechnology to Address Forest Health from the USA National Academy of Sciences that has identified biotechnologies as a key tool for helping to manage forest health and associated pest epidemics.

ASPB has studied and endorsed the petition.

Alerts to tens of thousands of scientists sent by American Association for the Advancement of Science - AAAS (worlds largest general scientific society)



AAAS | Policy Alert

Petition Launched to Change Certification of Biotechnology Forest Research

A committee of forest biotechnologists from around the world, which includes several AAAS honorary fellows, have launched a petition to change certification rules for forests to enable field research on gene-edited and genetically engineered trees. Currently, private certification systems include a ban on research using biotechnology tools in forest research. The petition comes on the heels of a recent report from the National Academies that discusses the importance of biotechnology research to help improve forest health. For additional background, visit the petition website. (**BACK TO THE TOP**)

1,161 signatures from all over the globe, majority PhDs

Support modern forest biotechnology research

May 30 2018 Cornell Alliance for Science Closed on Jun 11 2019

Letter published in *Science* about it (September 2019)

Certification for gene-edited forests

Forest certification bodies were established to provide consumers with confidence that they are purchasing
sourced wood products. Over
hectares of forests, or about
l forest area, are certified
rgest certification systems
ver, certification bodies have
excluded all genetically
or gene-edited (GE) trees from
, including from field research
lands that is essential for
ng local benefits and impacts
ing forest biotechnology
om around the world, with
of more than 1000 globally
atories to a recent detailed
call for all forest certification
romptly examine and modify
s.
ce mounting stresses posed
ests and climate change (*6*).

Engineering, and Medicine recently completed an in-depth study on forest health and biotechnology, concluding that the potential benefits are numerous and rapidly increasing (*12*). Our forests are in dire need of assistance, and GE trees hold tremendous potential as a safe and powerful tool for promoting forest resilience and sustainability.

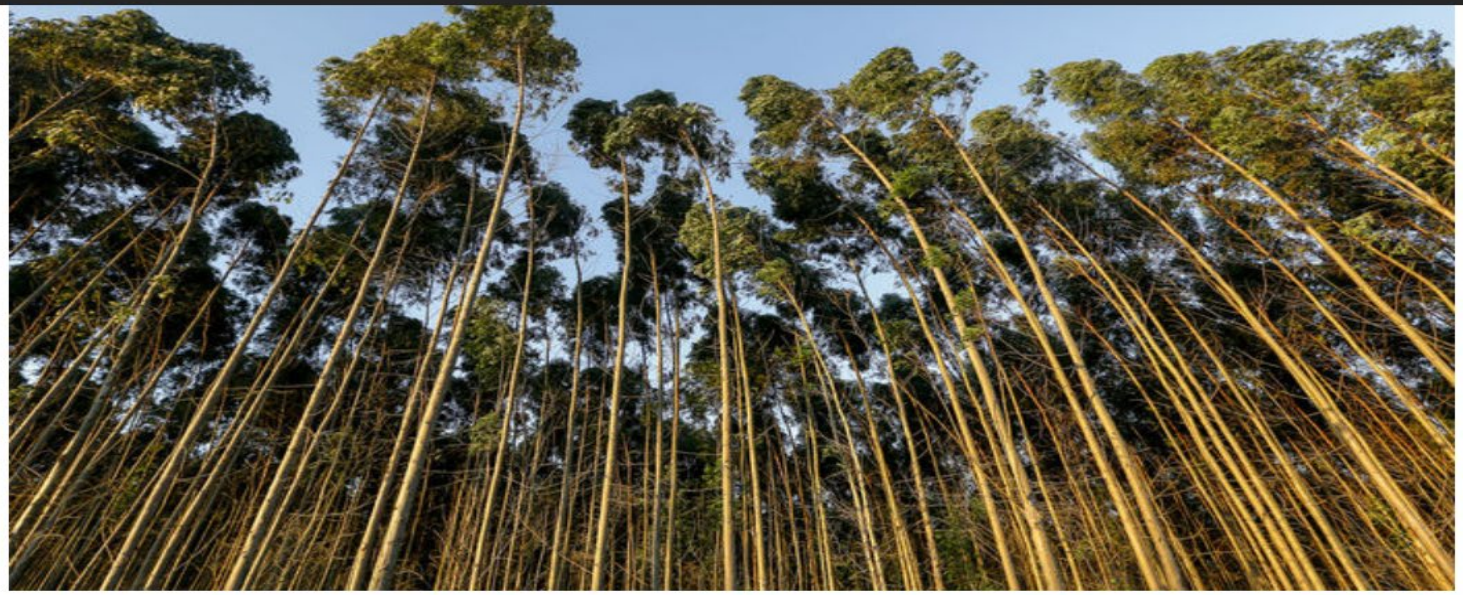
Steven H. Strauss[1]*, Wout Boerjan[2], Vincent Chiang[3], Adam Costanza[4], Heather Coleman[5], John M. Davis[6], Meng-Zhu Lu[7], Shawn D. Mansfield[8], Scott Merkle[9], Alexander Myburg[10], Ove Nilsson[11], Gilles Pilate[12], William Powell[13], Armand Seguin[14], Sofia Valenzuela[15]

[1]Department of Forest Ecosystems and Society, Oregon State University, Corvallis, OR 97331, USA. [2]Department of Plant Biotechnology and Bioinformatics, Ghent University and Center for Plant Systems Biology, VIB, 9052 Ghent, Belgium. [3]Department of Forestry and Environmental Resources, North Carolina State University, Raleigh, NC 27695, USA. [4]Chapel Hill, NC 27517, USA. [5]Department of Biology, Syracuse University, Syracuse, NY 13244, USA. [6]School of Forest Resources and Conservation, University of Florida, Gainesville, FL 32611, USA. [7]State Key Laboratory of Subtropical Silviculture, School of Forestry and Biotechnology, Zhejiang A&F University, Hangzhou 311300, China. [8]Forest Sciences Centre, University

standard-pefc-st-2002-2013.

Gene-edited and genetically engineered trees, such as these poplars, should be allowed in certified forests.

News article also published in Science



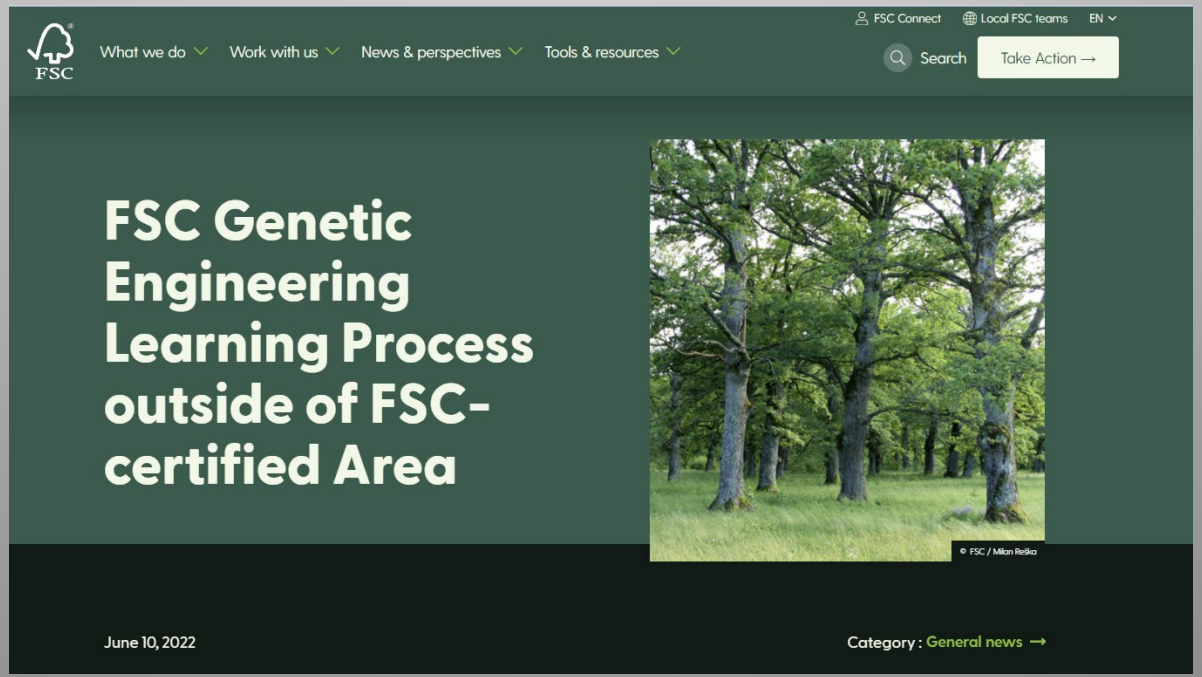
Productivity of eucalyptus plantations could be increased with trees genetically modified for faster growth.
CASADAPHOTO/SHUTTERSTOCK.COM

Scientists say sustainable forestry organizations should lift ban on biotech trees

By Erik Stokstad | Aug. 23, 2019 , 5:45 PM

The result: It helped to initiate a reconsideration of GMO policy by FSC

Led to the **“FSC GE learning process”** as an “associated use” – whereby a certified company can apply to do research, on non-certified land, but not use any GMO materials in products



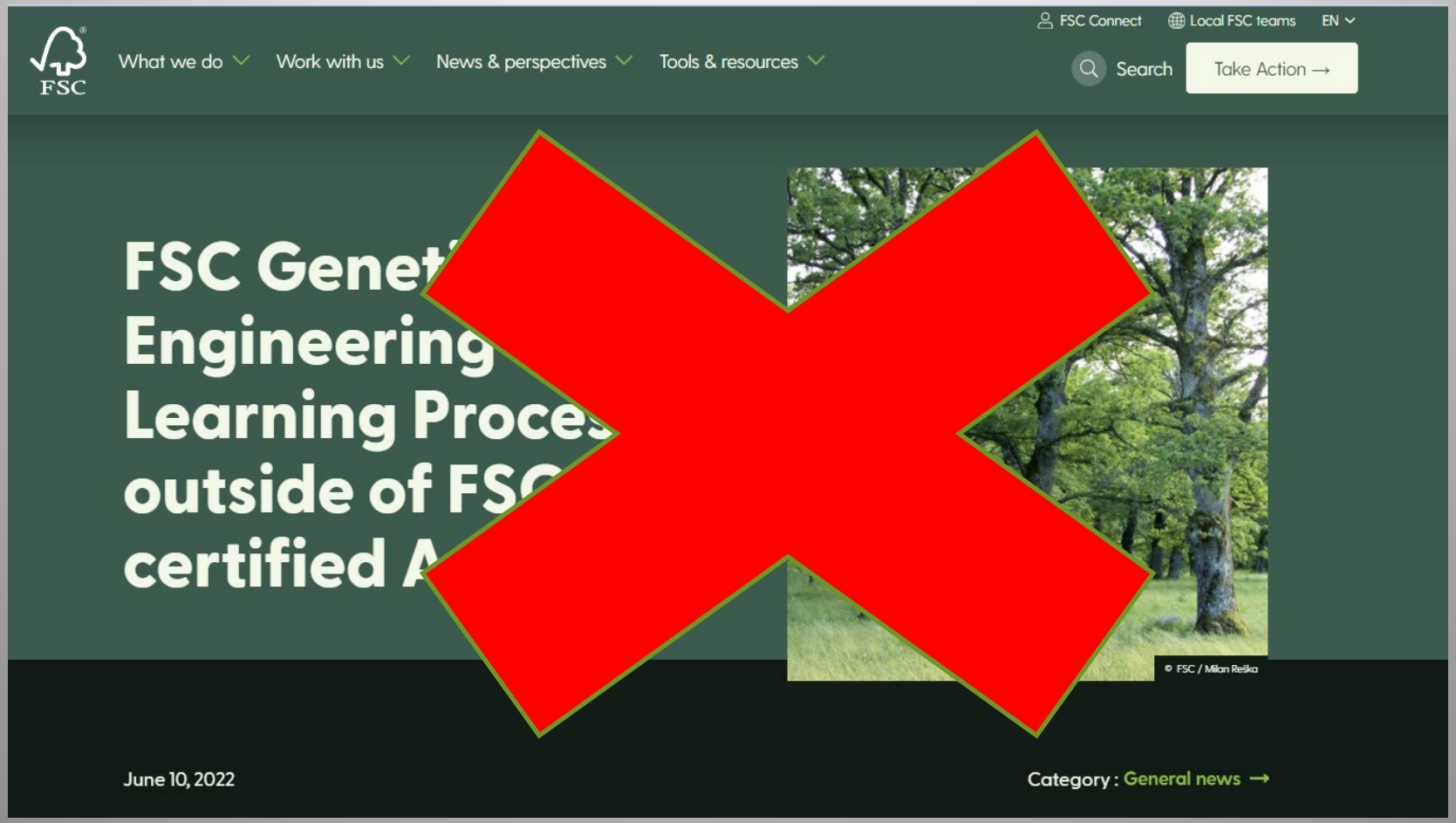
Is this a good thing?

A small, slow, and limited “start,” with strong emphasis on risk management vs. opportunity assessment

What is the value given extensive research already published? Is this better than the last ~30 years of stasis, or just a further delay tactic?

Diverse expert panel formed, deliberated for nearly two years to develop a framework proposal – I was the only biotech member

The outcome: The process canceled in March 2023 due to internal political fights



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The problem of gene flow

- Gene flow, either as seeds, or via pollen where there are compatible relatives, creates special problems for GE acceptance
- Long distance dispersal of pollen, and sometimes seeds, common for trees
- Movement onto other lands and products where their presence is unwelcomed or economically problematic
- Potential impacts on wild populations, ferals, exotics
  - Long term, evolutionary change an ethical concern?
  - Oligogenic/domestication changes trivial in face of vast evolutionary history and polygenic adaptations in wild?
  - Trivial in face of climate perturbations?
  - Focus instead on near-term weediness/harm?

Are containment technologies the answer? My lab has studied many technologies over the years

CRISPR to the rescue ?

Plant Biotechnology Journal
Open Access

Research Article | Open Access

Genetic containment in vegetatively propagated forest trees: CRISPR disruption of *LEAFY* function in *Eucalyptus* gives sterile indeterminate inflorescences and normal juvenile development

Estefania Elorriaga, Amy L. Klocko, Cathleen Ma, Marc du Plessis, Xinmin An, Alexander A. Myburg, Steven H. Strauss

First published: 27 March 2021 | https://doi.org/10.1111/pbi.13588 | Citations: 1

But sterility can also have serious impacts on biodiversity, impair breeding, and with complex public perception

New Phytologist

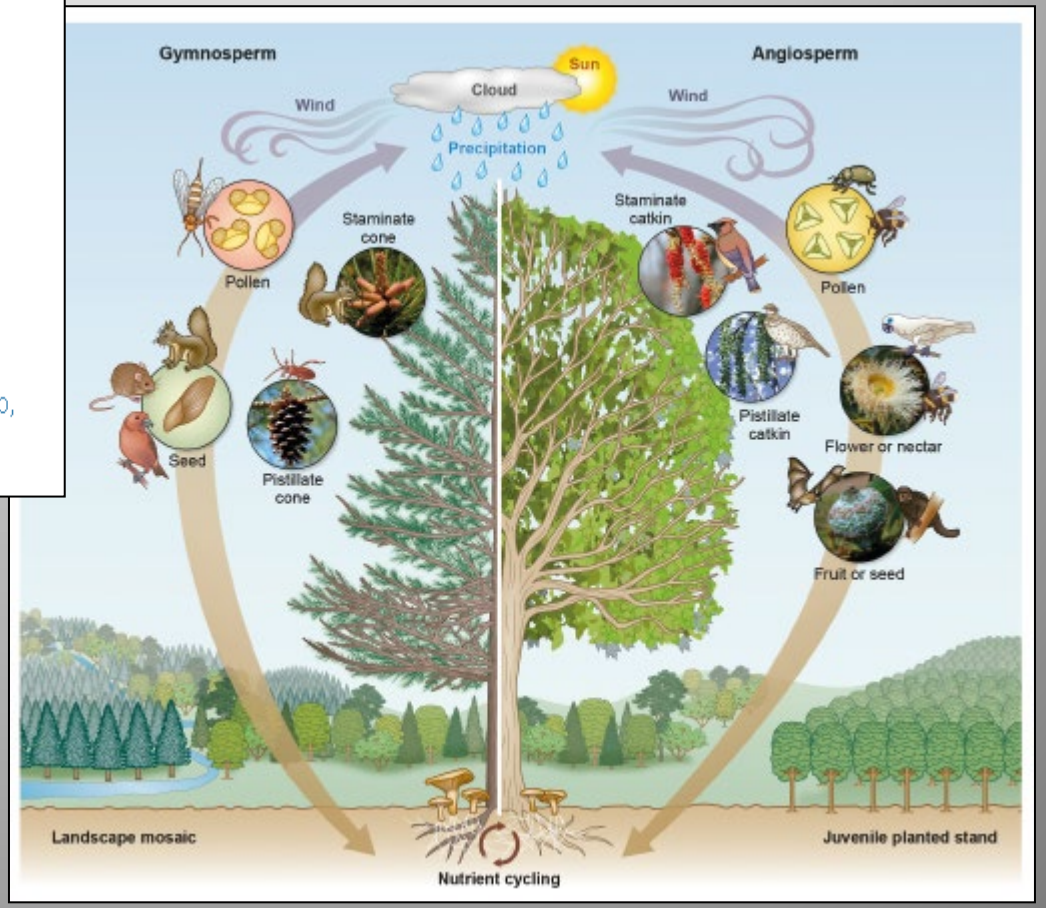
Explore this journal >

Tansley review

Reproductive modification in forest plantations: impacts on biodiversity and society

Steven H. Strauss ✉, Kristin N. Jones, Haiwei Lu, Joshua D. Petit, Amy L. Klocko, Matthew G. Betts, Berry J. Brosi, Robert J. Fletcher Jr, Mark D. Needham

Also need long term studies to demonstrate efficacy and stability for recognition by regulatory systems



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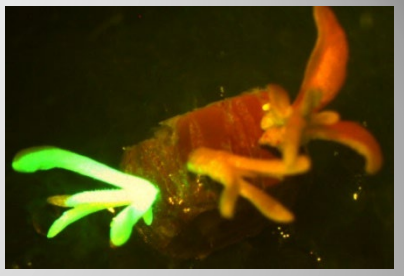
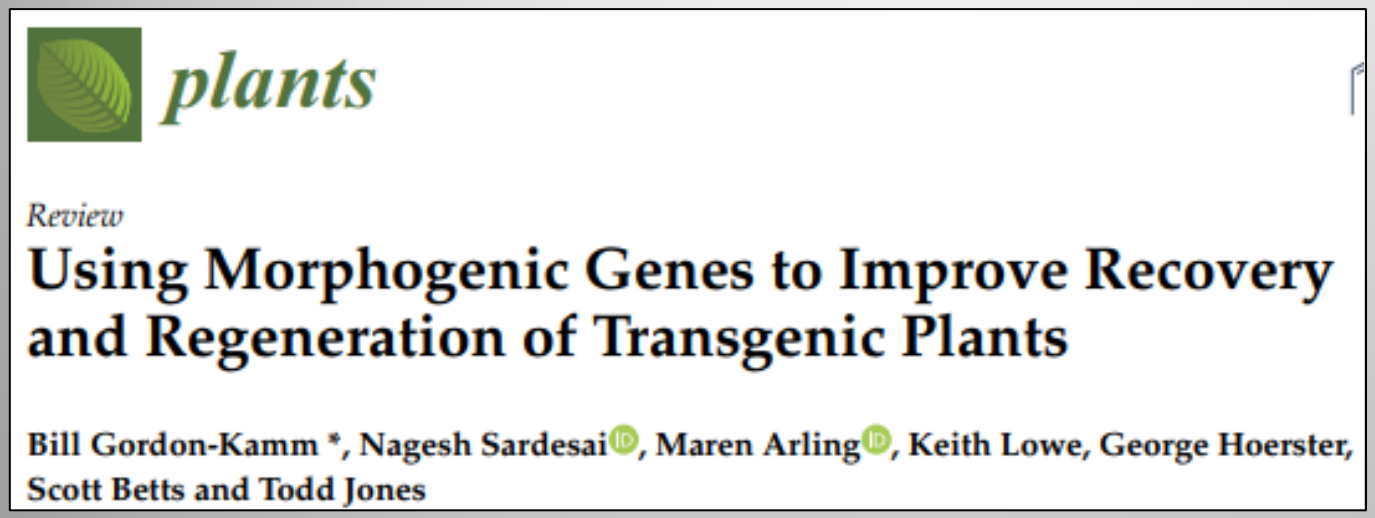
The problem of effective transformation / editing



- Transformation (and regeneration) difficult, costly, or impossible in many genotypes
- Forest trees highly diverse, tissues often recalcitrant to typical treatments due to developmental stage or physiology
- Problematic for obtaining “clean” gene edited progeny from diverse genotypes to avoid GMO regulation

“DEV” genes can work, but need much more research

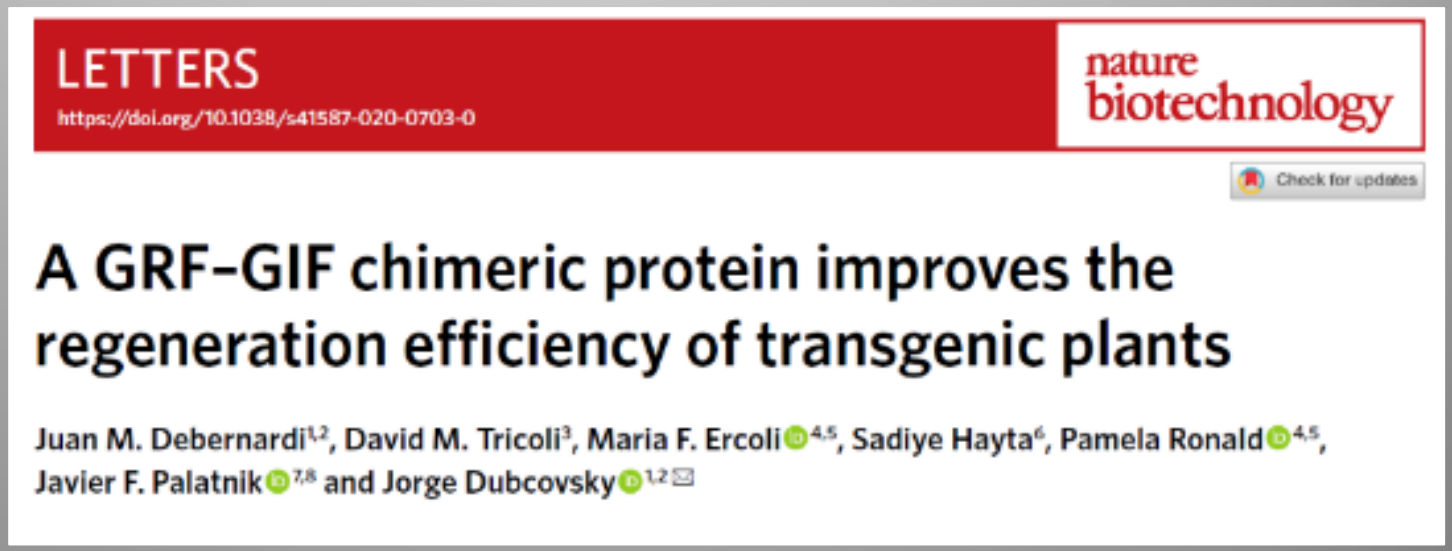


plants

Review

Using Morphogenic Genes to Improve Recovery and Regeneration of Transgenic Plants

Bill Gordon-Kamm *, Nagesh Sardesai, Maren Arling, Keith Lowe, George Hoerster, Scott Betts and Todd Jones

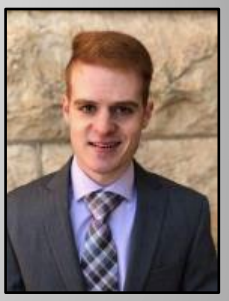


LETTERS
https://doi.org/10.1038/s41587-020-0703-0
nature biotechnology
Check for updates

A GRF–GIF chimeric protein improves the regeneration efficiency of transgenic plants

Juan M. Debernardi[1,2], David M. Tricoli[3], Maria F. Ercoli[4,5], Sadiye Hayta[6], Pamela Ronald[4,5], Javier F. Palatnik[7,8] and Jorge Dubcovsky[1,2]

Populus GRF-GIF promoted transgenic shoot regeneration in recalcitrant *P. alba* '6K10'

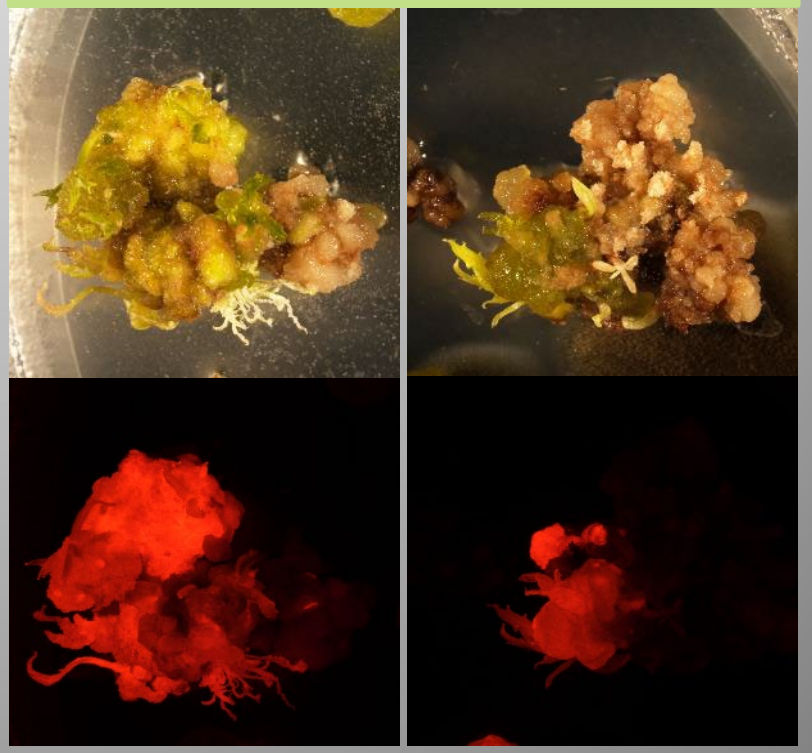


Control (dsRed)

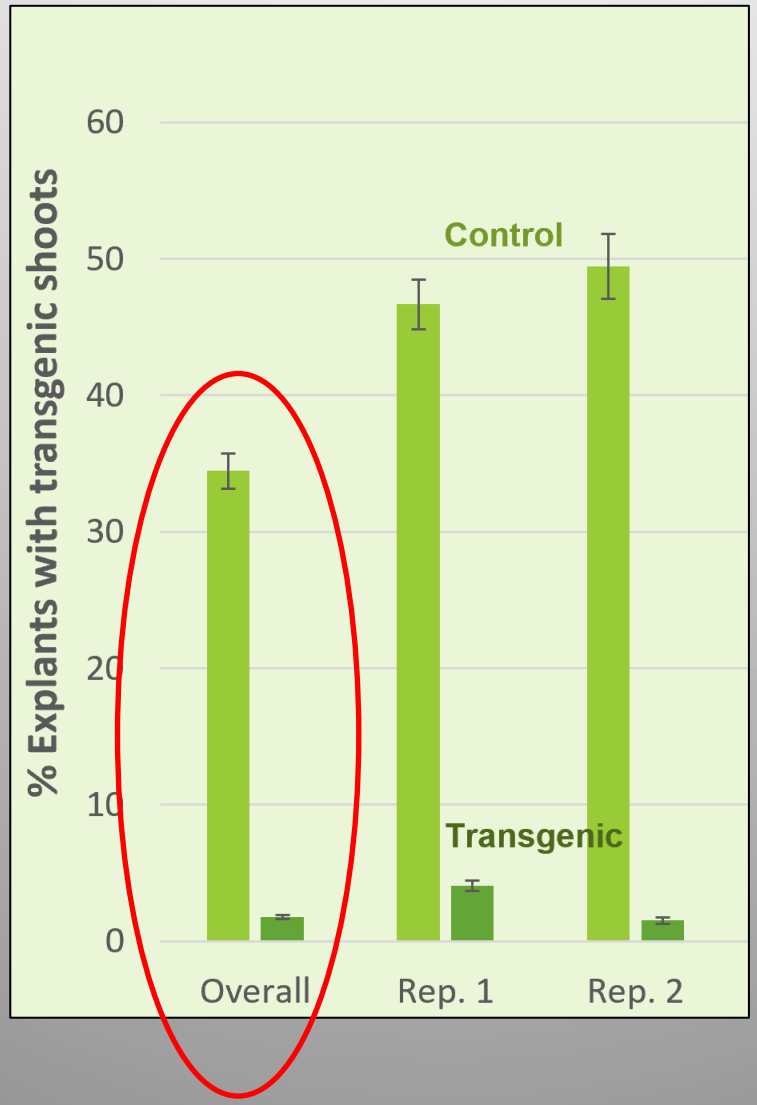
Bright field

dsRed

Poplar GRF4-GIF1



But it strongly inhibited shoot formation in another poplar clone



No simple solutions to transformation of most woody plants yet – but many exciting developments

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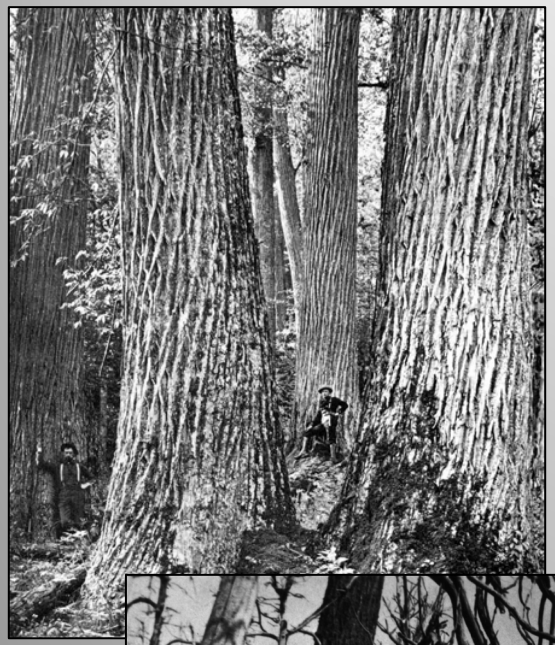
- Innovations proposed

Helping wild and planted trees cope with pests?



Traces of the emerald ash borer on the trunk of a dead ash tree in Michigan, USA. This non-native invasive insect from Asia threatens to kill most North American ash trees.

BIOTECHNOLOGY

Genetically

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en H. Strauss[1]*, Adam Cos

d Séguin[2]

nsive genetic modificatio

ding practice in agriculture, and,

some species, in woody plant horti-

ure and forestry (*1*). Current regula-

systems for genetically engineered

Difficulties of conventional tree breeding make genetic engineering (GE) methods relatively more advantageous for forest trees than for annual crops (*3*). Obstacles

ew forest tree species

GE in the foreseeable

l market obstacles pre-

m even being subjects

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cial activity: Only two

poplars are authorized

n small areas in China

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AND MISGUIDED.

nce reports state that

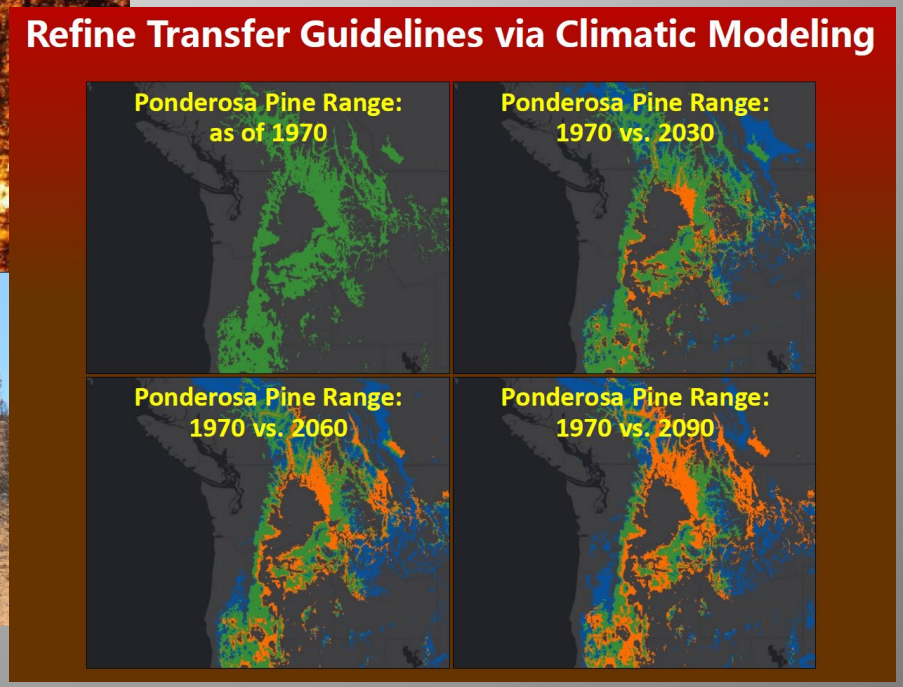
the GE method is no more risky than conventional breeding, but regulations around the world essentially presume that GE is hazardous and requires strict containment

Emerald ash border is spreading throughout the USA, devastating wild and plants ash trees

Why little biotech ash research underway given the borer "pandemic"?

- Transformation/regeneration difficult – very little investment to date for ash
- Molecular basis of resistance unclear
  - Gene edit + transgenics in the field would advance science greatly
- Regulatory barriers to field research--trait takes years to express and extensive field tests needed – USDA Secure RSR process a key capability ?
- But still large regulatory barriers to commercial use – to EPA any kind of GE resistant tree would be a new PIP "pesticide" (no EPA Secure equivalent on horizon)
- Market restrictions: "Green" certification systems

Urgency! Devastating fires generate immediate need for climate-informed seed – let alone advanced breeding or biotech seed



Agenda

- Definitions and overview
- The social thicket
- Gene flow as a bioethical dilemma
- Transformation/editing recalcitrance
- Climate change/pest urgency
- Innovations proposed

Fundamental change is needed

Proc. Nat. Acad. Sci. USA
Vol. 72, No. 6, pp. 1981–1984, June 1975

Summary Statement of the Asilomar Conference on Recombinant DNA Molecules*

PAUL BERG†, DAVID BALTIMORE‡, SYDNEY BRENNER§, RICHARD O. ROBLIN III¶, AND MAXINE F. SINGER||

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OPINION MEETINGS THAT CHANGED THE WORLD

ESSAY

Asilomar 1975: DNA modification secured

The California meeting set standards allowing geneticists to push research to its limits without endangering public health. Organizer **Paul Berg** asks if another such meeting could resolve today's controversies.

A fundamental, international change is needed -- to shift focus away from the method to high risk:benefit traits, and structured to address the high costs of failure to innovate due to expansive definitions of risk

Foundational changes in laws or regulations

Ending event-based regulation of GMO crops

To the Editor:

Getting regulation of agricultural biotechnologies right is no simple task. Stringent regulations for genetically modified organisms (GMOs) in the European Union (EU: Brussels) have nearly stifled the use of biotech crops on farms or in derived foods there, and in the United States the diversified 'Coordinated Framework' has produced a strange patchwork of rules, exceptions and lengthy delays. As the Editorial in the December issue highlights[1], the US Executive Branch has launched a process to reform its regulatory structure, calling for an integrated system that recognizes and balances safety, environment, innovation and economic growth[2]. On the heels of the release of a White House memo, the US House of Representatives passed the Safe and Accurate Food Labeling Act of 2015, which is on its way to the Senate for consideration. Contrary to current regulations, this legislation would explicitly preempt state-by-state labeling and require the US Food and Drug Administration (FDA) to conduct a safety review for all GMOs entering commerce[3]. This recent activity by both the executive and legislative branches provides a welcome opportunity to take a fresh look at

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- End event-by-event regulation everywhere, NOW!
- Allowance for gene flow / low level admixture at workable levels except where there is a clear and evidence-based threat to food supply or environment, such as....
  - Probable allergens in food crops
  - Genes that can tangibly exacerbate control of already problematic weeds

Foundational changes in laws or regulations

- NOT based on method but on the trait and host organism – and a high probability of harm when compared to...
  - Harm from the absence of a biotech solution
  - Conventional breeding methods, risks, and uncertainties
- Standard research-scale, not GMO-stringent, management of gene flow
  - Removal of todays powerful GMO/gene edit liabilities – especially for urgent/important cases

Summary: What is needed to make forest biotech relevant?

- Basic science on gene-trait controls, gene control tools, and synthetic biology -- in important trees and crops
- Overcome the transformation bottleneck – research new tools (e.g., DEV genes and viral editing tools)
- Foundational legal and marketplace innovations to spur public and private investment

Summary: What is needed to make forest biotech relevant?

- Extensive, public field research with a wide variety of production and stress-reduction genes—integrated with conventional breeding—directed toward the climate crisis in all it's manifestations
- Outcome: Rational, timely integration of biotech genes into breeding programs to help mitigate climate crisis, bolster productivity
- **To matter given the pace of population growth and climate/pest changes, the social and biological innovations must be rapid and foundational, not incremental**


Thank you