Tree biotech for greenhouse gas mitigation

A confluence of urgency, technology, and social dysfunction

Cosmos Club, Washington, D.C.
May 2022

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Goals for today

- The buzz
- What is biotech and what is the context?
- A closer look at two lead examples
- The reality of urgency and obstacles

Plenty of buzz of late

To fight climate change, a biotech firm has genetically engineered a very peppy poplar

But fast-growing transgenic tree faces long road to real-world use

23 FEB 2022 • 9:00 AM • BY GABRIEL POPKIN

WIRED

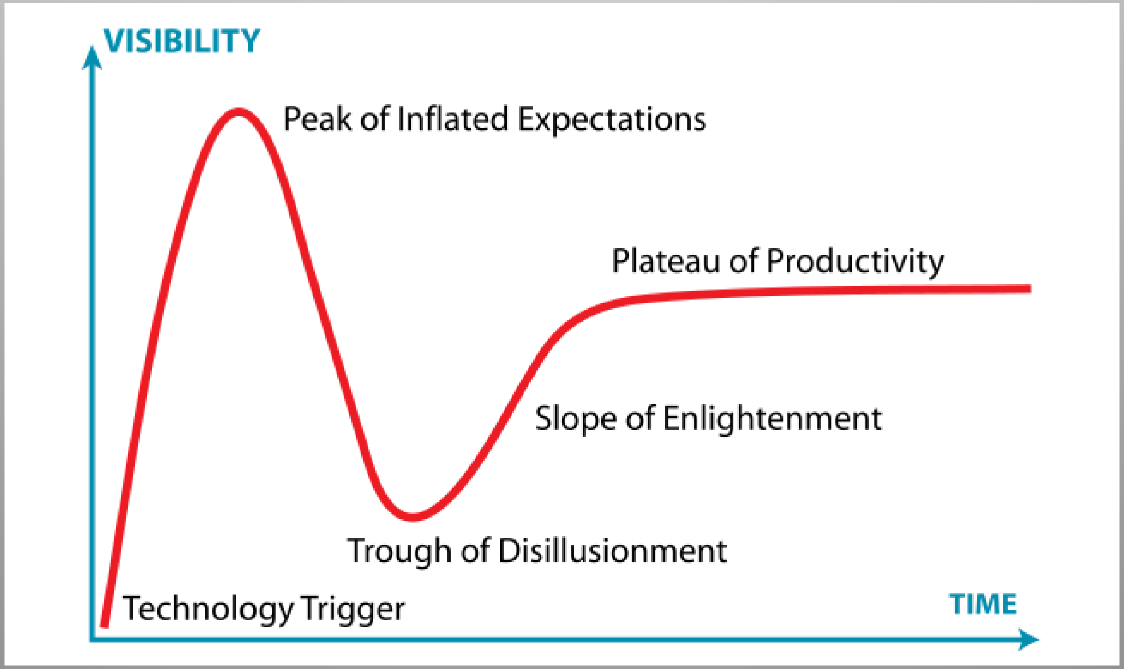
MATT REYNOLDS SCIENCE MAR 28, 2022 7:00 AM

A Bold Idea to Stall the Climate Crisis—by Building Better Trees

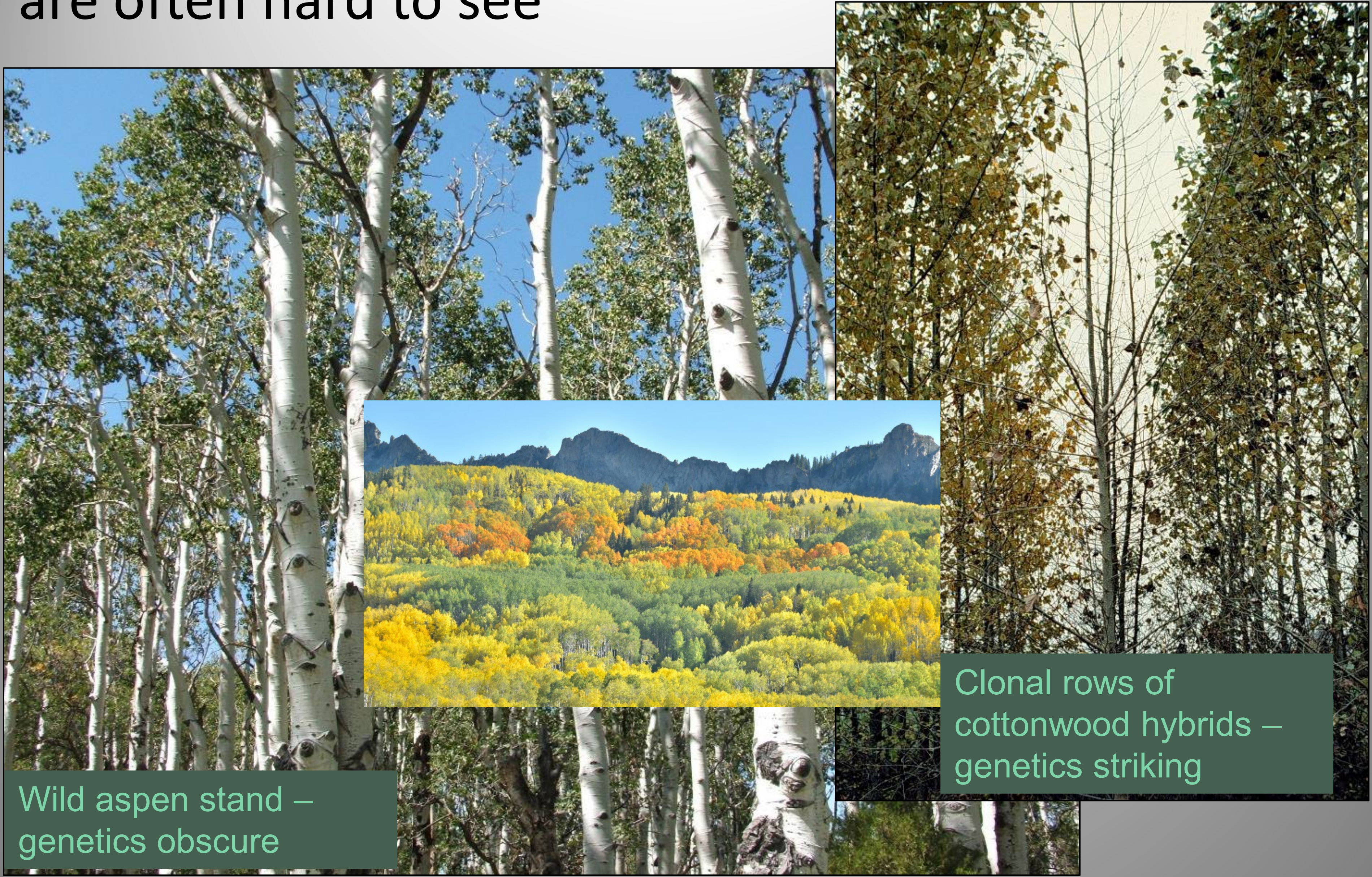
Changing the genetic makeup of trees could supercharge their ability to suck up carbon dioxide. But are forests of frankentrees really a good idea?

Fascinating and simple

- We are in big climate trouble
- We don't want to make sacrifices
- We need big solutions
- Science and tech to the rescue!
- The Gartner Hype Cycle rides again!



Forest trees are super diverse, but genetic effects are often hard to see

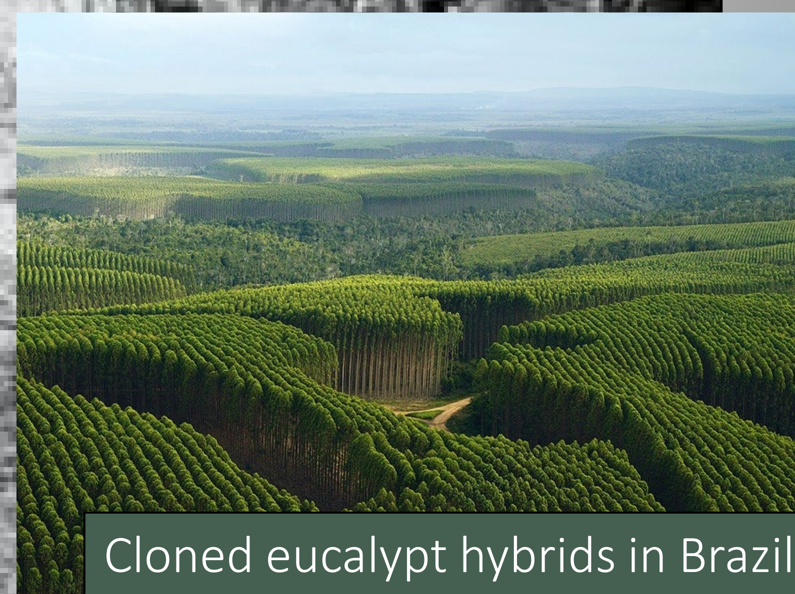


Wild aspen stand – genetics obscure

Clonal rows of cottonwood hybrids – genetics striking

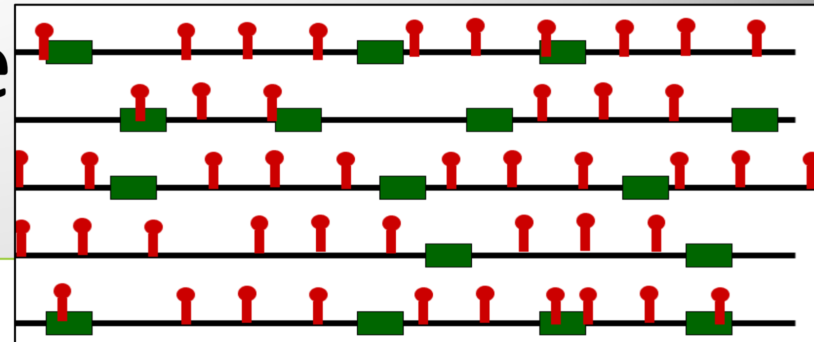
Conventional breeding can have powerful effects

One generation of breeding Monterey pine in New Zealand made striking changes in growth & form



Cloned eucalypt hybrids in Brazil

Genomic selection "revolution" for breeding and climate adaptation



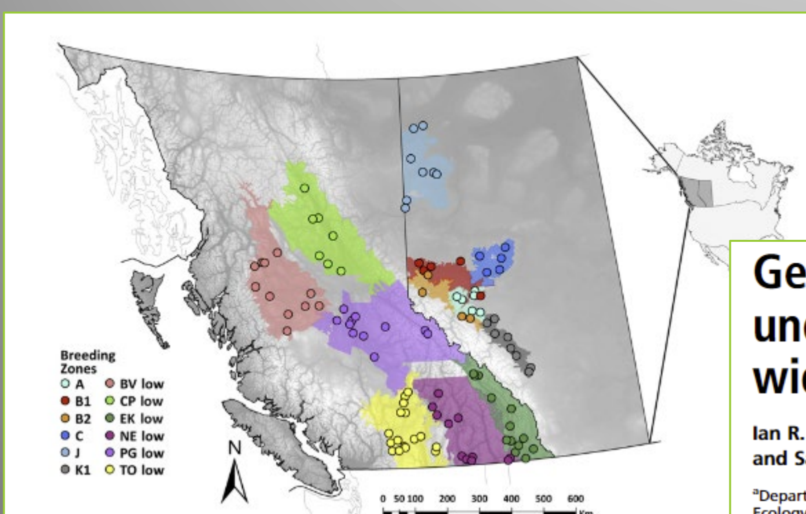
Springer Link

Original Paper | Published: 05 October 2010

Genomic selection in forest tree breeding

Dario Grattapaglia & Marcos D. V. Resende

Tree Genetics & Genomes **7**, 241–255 (2011) | Cite this article

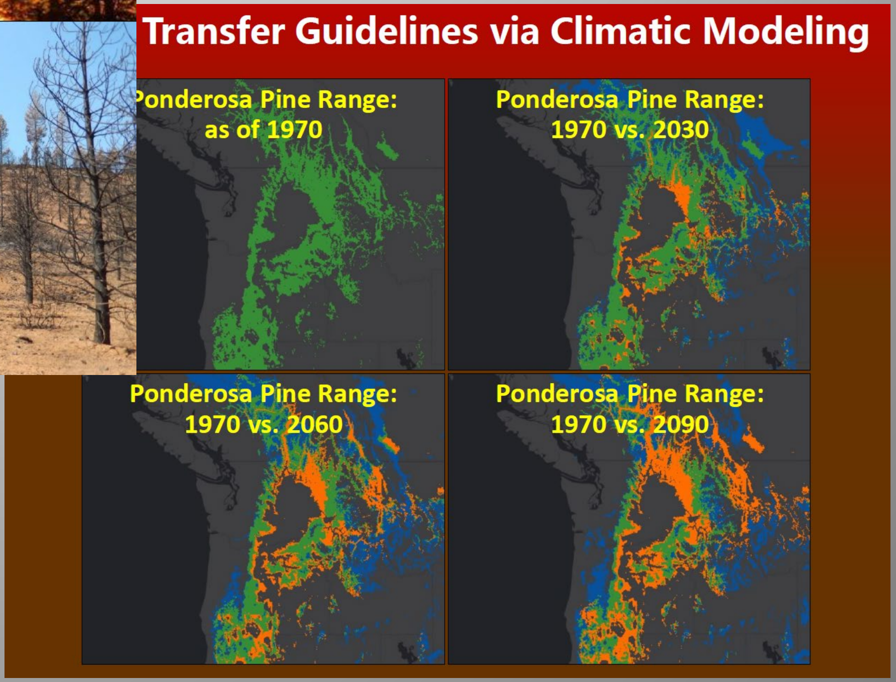


Genome-wide shifts in climate-related variation underpin responses to selective breeding in a widespread conifer

Ian R. MacLachlan[a,b,1], Tegan K. McDonald[c], Brandon M. Lind[a], Loren H. Rieseberg[d], Sam Yeaman[c], and Sally N. Aitken[a]

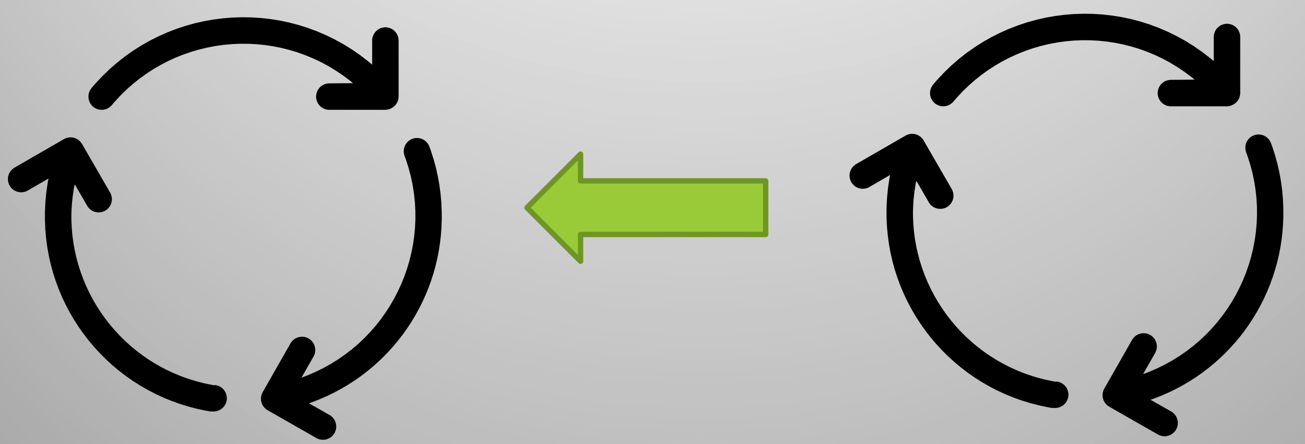
[a]Department of Forest and Conservation Sciences, Faculty of Forestry, University of British Columbia, Vancouver, BC V6T 1Z4, Canada; [b]Department of Ecology and Conservation Biology, Texas A&M University, College Station, TX 77843; [c]Department of Biological Sciences, University of Calgary, Calgary, AB T2N 1N4, Canada; and [d]Department of Botany, University of British Columbia, Vancouver, BC V6T 1Z4, Canada

Devastating fires generate immediate need for climate-informed seed



Relationship of breeding and biotech

Breeding populations | **Biotech innovations**

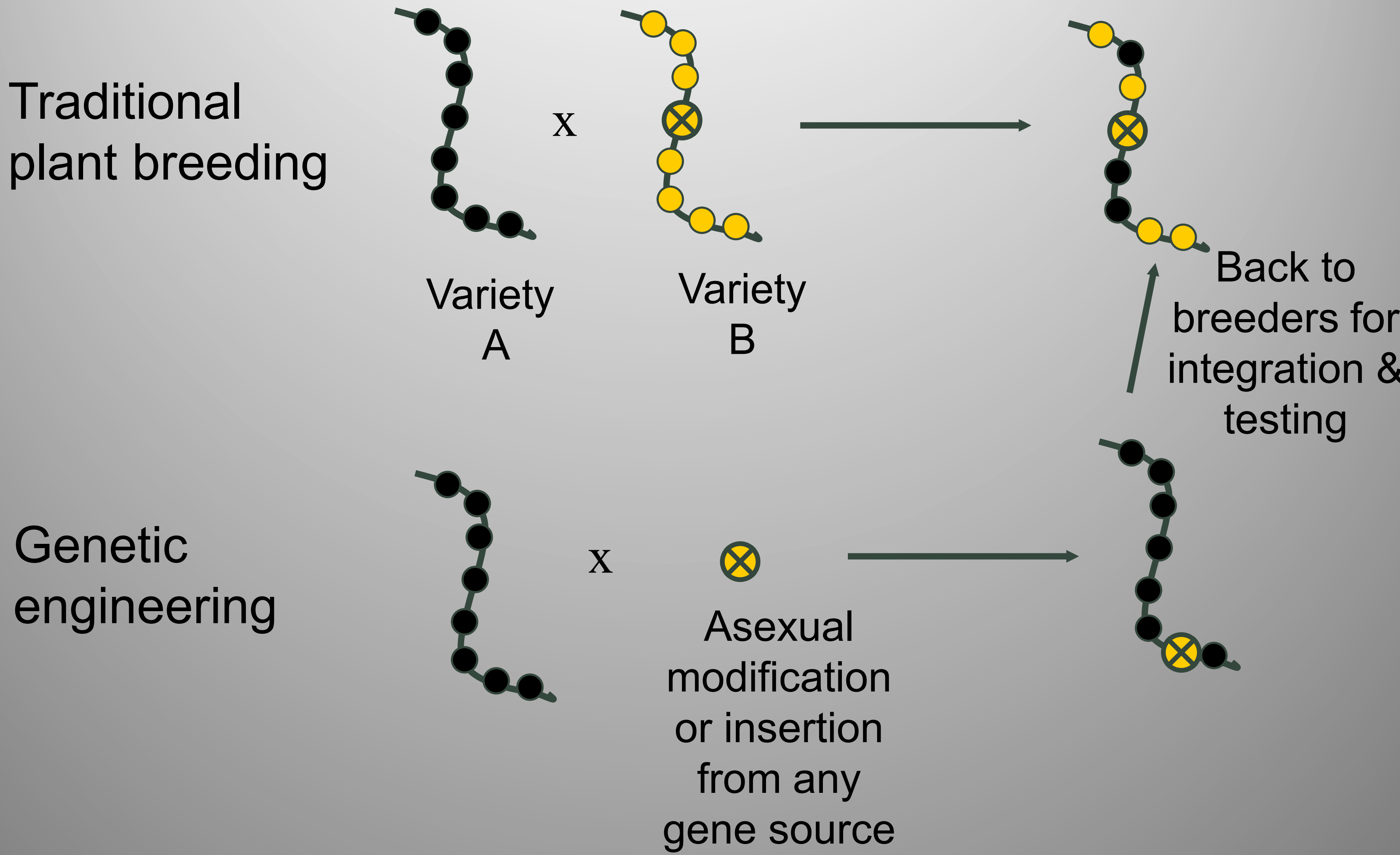


Polygenic:
Growth rate and adaptation

Oligogenic:
Specific modifications and novel traits

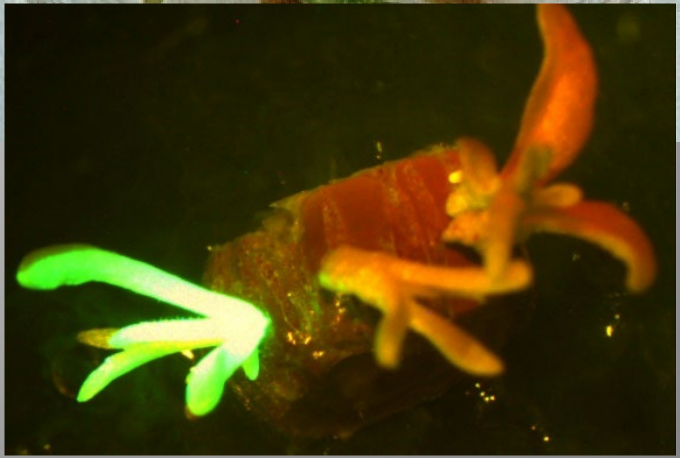
These need to be integrated in a way that does not slow down conventional breeding, with its growing power and urgency in a climate changed world

"Biotech" for public refers to gene editing or genetic engineering (GE), not genomic methods



Biotech (GE) defined

- It's a <u>method</u>: Native or "foreign" genes, modified traits or new traits
- Genes in chemical form, changed in a test tube, and inserted asexually -- vs. making crosses or random mutations in conventional breeding
- Used to add new genes or to modify native genes (CRISPR)
- The dogma: Relatively simple traits can be designed, but without constraints from native gene pools



Gene editing

- A gene you insert to change other genes in the genome
- Gives specific, efficient modification of native genes
- CRISPR the main method out there
- Works well everywhere!
- Routine now in science and biotech
- Not relevant for today’s cases!

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- **A closer look at two lead examples**
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Photosynthesis modified trees to increase carbon uptake?

Oregon State field trial

RESEARCH ARTICLE

Science

AAAS

PLANT SCIENCE

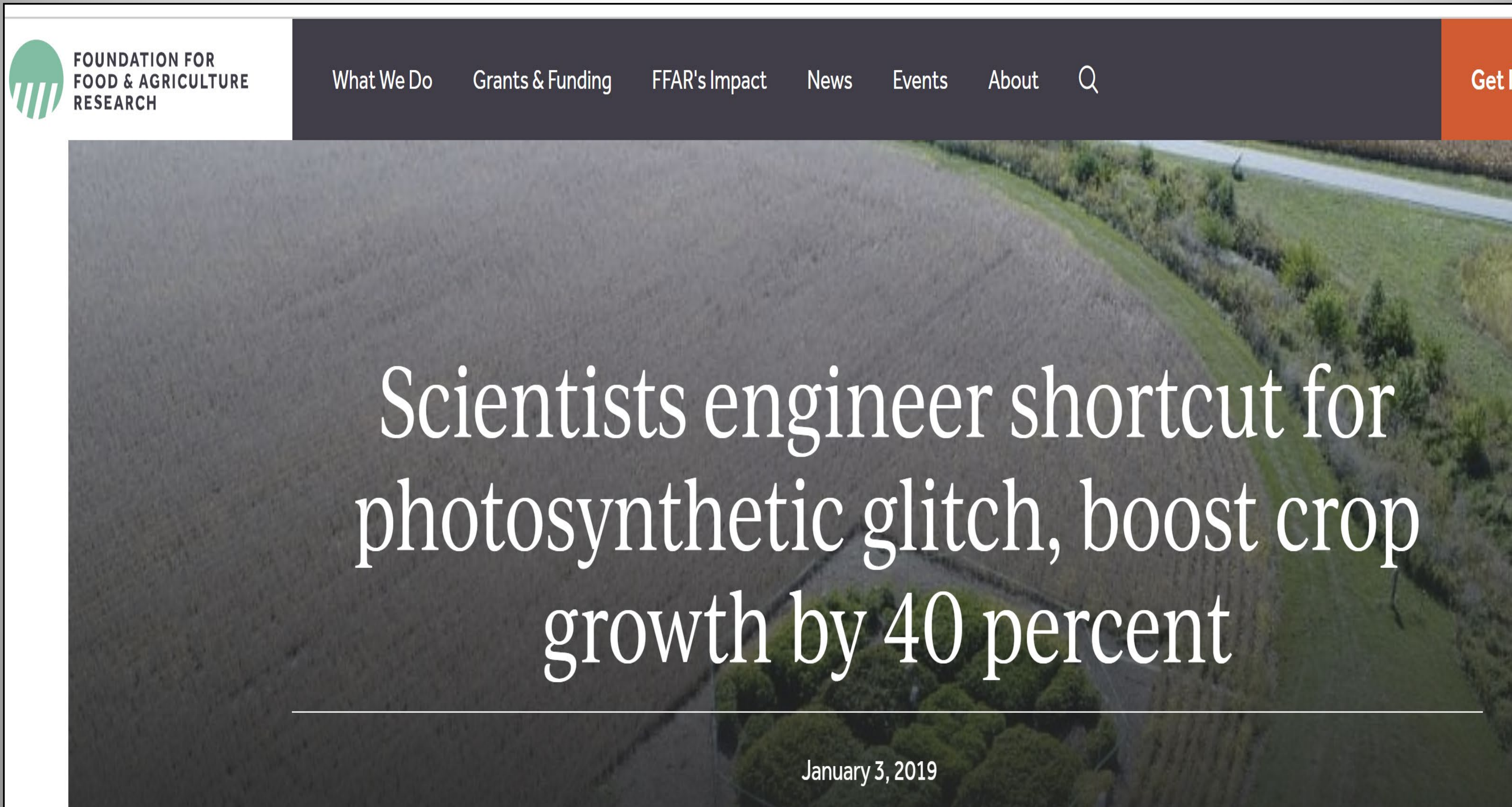
Synthetic glycolate metabolism pathways stimulate crop growth and productivity in the field

Paul F. South[1,2], Amanda P. Cavanagh[2], Helen W. Liu[3*], Donald R. Ort[1,2,3,4†]

Photorespiration is required in C_3 plants to metabolize toxic glycolate formed when ribulose-1,5-bisphosphate carboxylase-oxygenase oxygenates rather than carboxylates ribulose-1,5-bisphosphate. Depending on growing temperatures, photorespiration can reduce yields by 20 to 50% in C_3 crops. Inspired by earlier work, we installed into tobacco chloroplasts synthetic glycolate metabolic pathways that are thought to be more efficient than the native pathway. Flux through the synthetic pathways was maximized by inhibiting glycolate export from the chloroplast. The synthetic pathways tested improved photosynthetic quantum yield by 20%. Numerous homozygous transgenic lines increased biomass productivity between 19 and 37% in replicated field trials. These results show that engineering alternative glycolate metabolic pathways into crop chloroplasts while inhibiting glycolate export into the native pathway can drive increases in C_3 crop yield under agricultural field conditions.

Science Volume 363 / January 4, 2019

"In C3 crops such as wheat, rice, and soybeans, photorespiration reduces the photosynthetic conversion efficiency of light into biomass by 20 to 50%, with the largest losses occurring in hot dry climates where yield increases are sorely needed."



FOUNDATION FOR FOOD & AGRICULTURE RESEARCH

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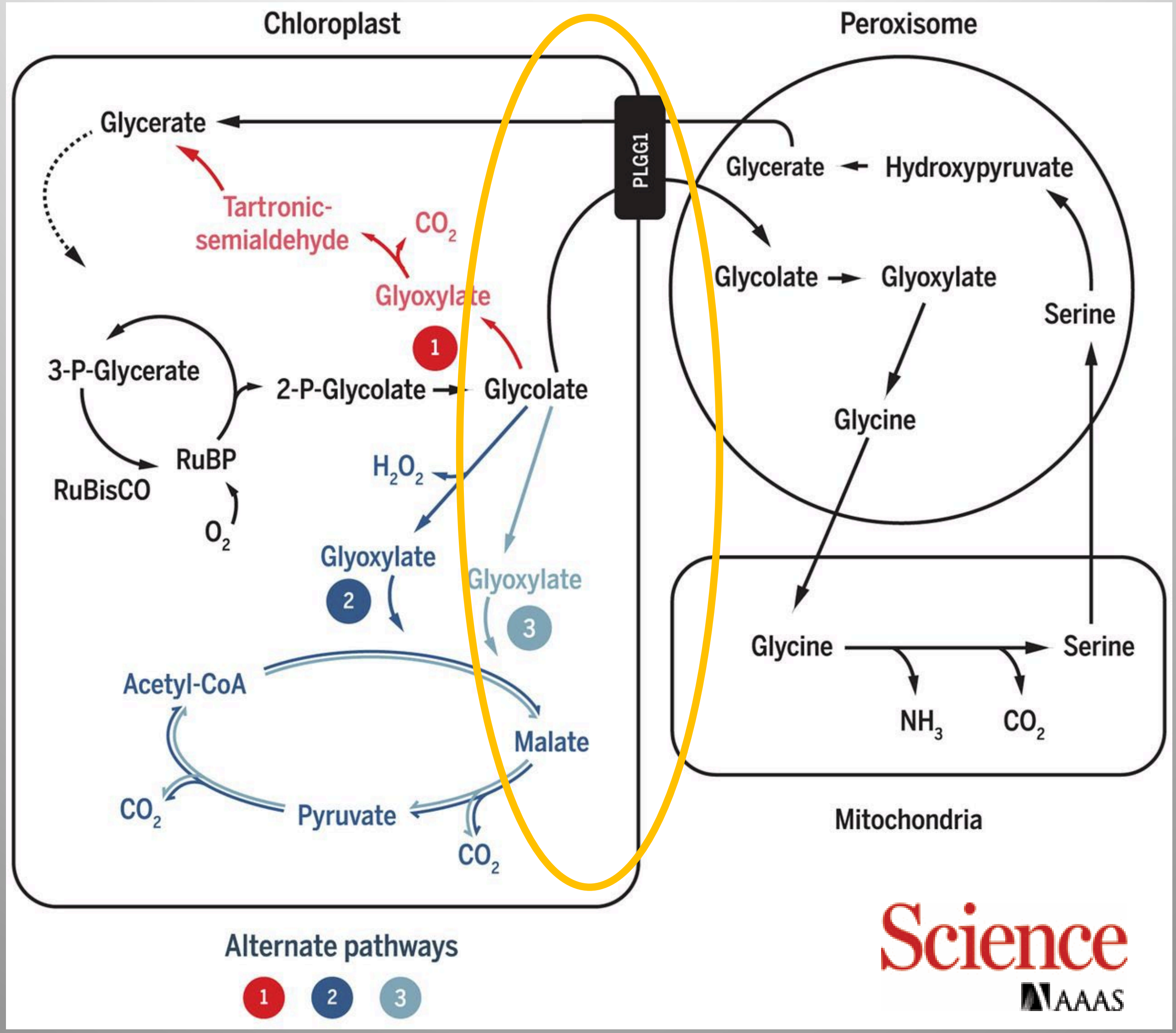
Scientists engineer shortcut for photosynthetic glitch, boost crop growth by 40 percent

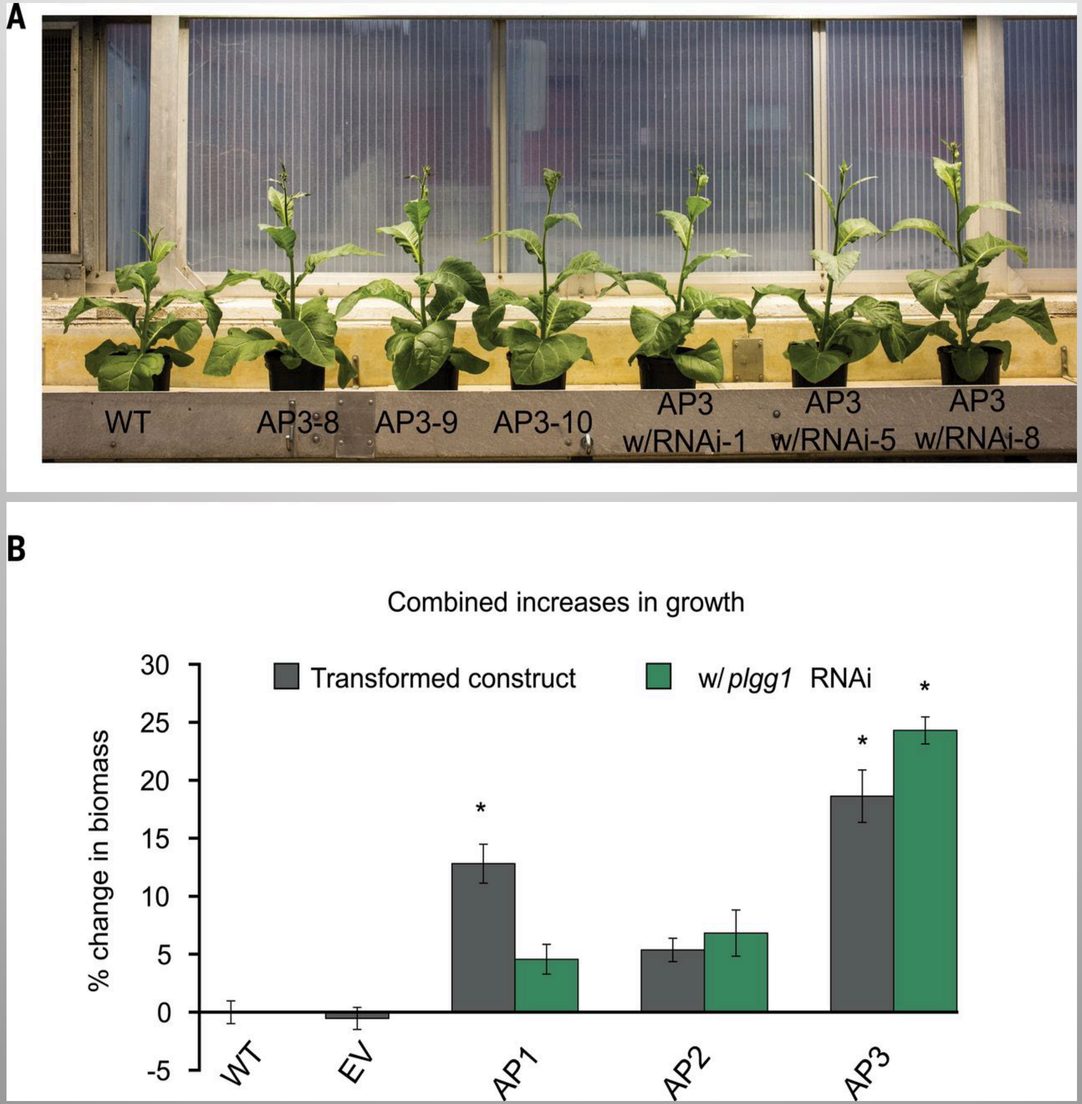
January 3, 2019

Alternative photorespiratory pathways tested in tobacco



Paul F. South et al. Science 2019;363:eaat9077

Some lines increase biomass under greenhouse conditions - tobacco



Paul F. South et al. Science 2019;363:eaat9077

Science AAAS

Overall conclusions

- Engineering more efficient photorespiratory pathways into tobacco while inhibiting the native pathway markedly increased both photosynthetic efficiency and vegetative biomass
- Numerous homozygous transgenic lines increased biomass productivity between 19 and 37% in replicated field trials
- "We are optimistic that similar gains may be achieved and translated into increased yield in C3 grain crops because photorespiration is common to all C3 plants and higher photosynthetic rates under elevated CO2, which suppresses photorespiration and increases harvestable yield in C3 crops."

Similar results in poplar in greenhouse

Cold Spring Harbor Laboratory

bioRxiv

THE PREPRINT SERVER FOR BIOLOGY

New Results

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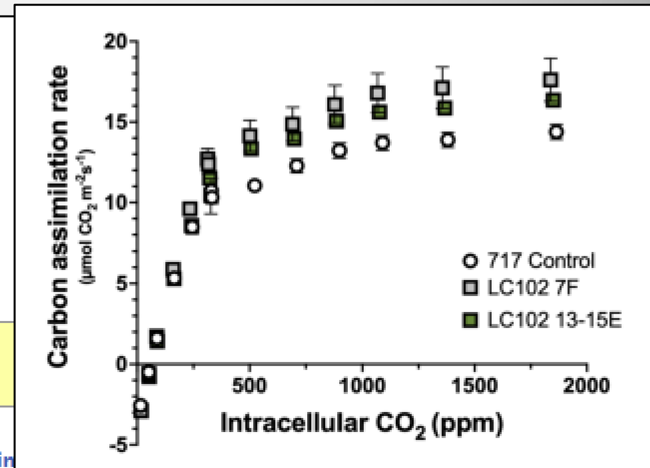
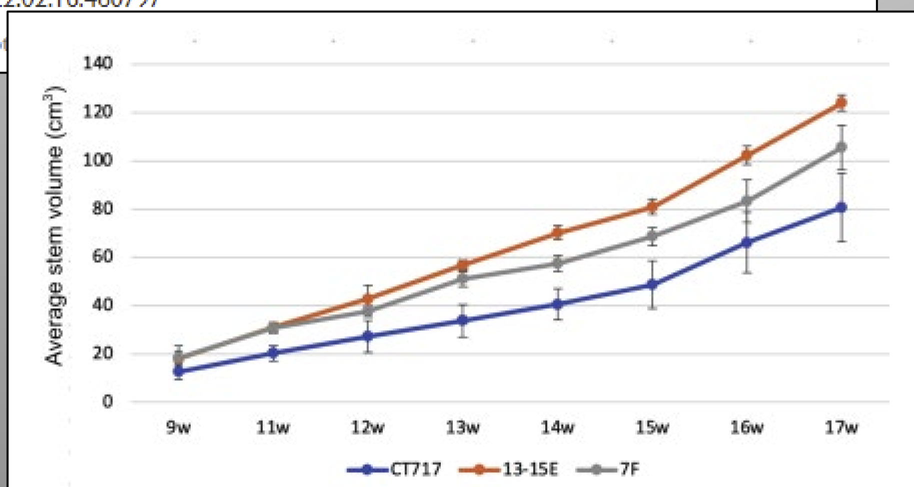
Enhanced photosynthetic efficiency for increased carbon assimilation and woody biomass production in hybrid poplar INRA 717-1B4

Living Carbon Team, Yumin Tao, Li-Wei Chiu, Jacob W. Hoyle, Jessica Du, Karli Rasmussen, Patrick Mellor, Christian Richey, Julie Kuiper, Madeline Fried, Rebecca A. Dewhirst, Dominick Tucker, Alex Crites, Gary A. Orr, Matthew J. Heckert, Damaris G. Vidal, Martha L. Orosco-Cardenas, Madeline E. Hall

doi: https://doi.org/10.1101/2022.02.16.480797

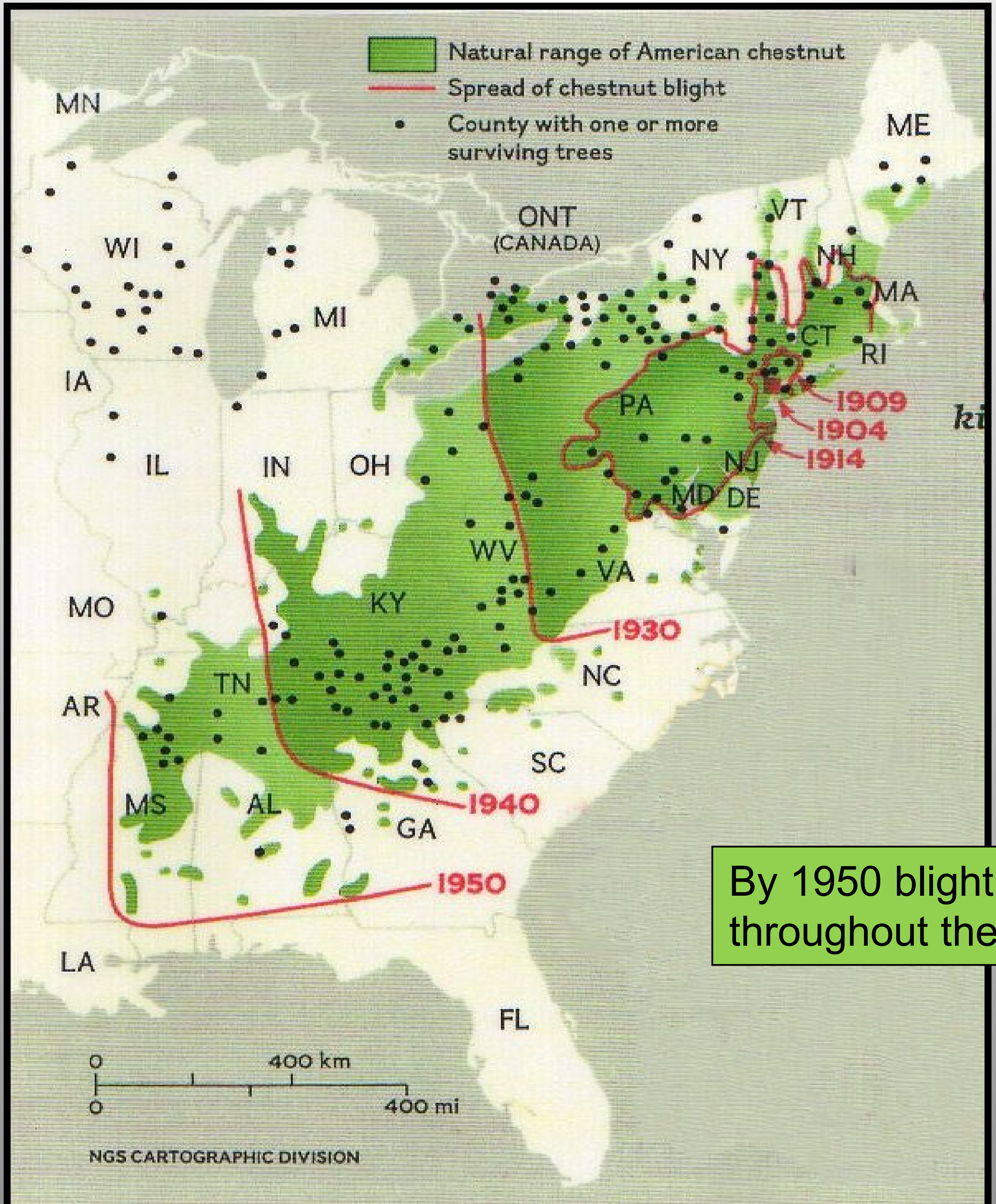
This article is a preprint and has not





Transgenic restoration of the American chestnut

Thanks to Jared Westbrook, American Chestnut Foundation



By 1950 blight had spread throughout the species range

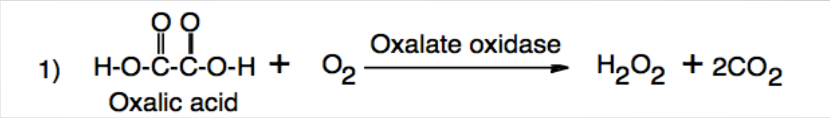
American chestnut is functionally extinct

Stems survive 10-15 years as stump sprouts in the forest understory, but species not reproducing in self sustaining populations

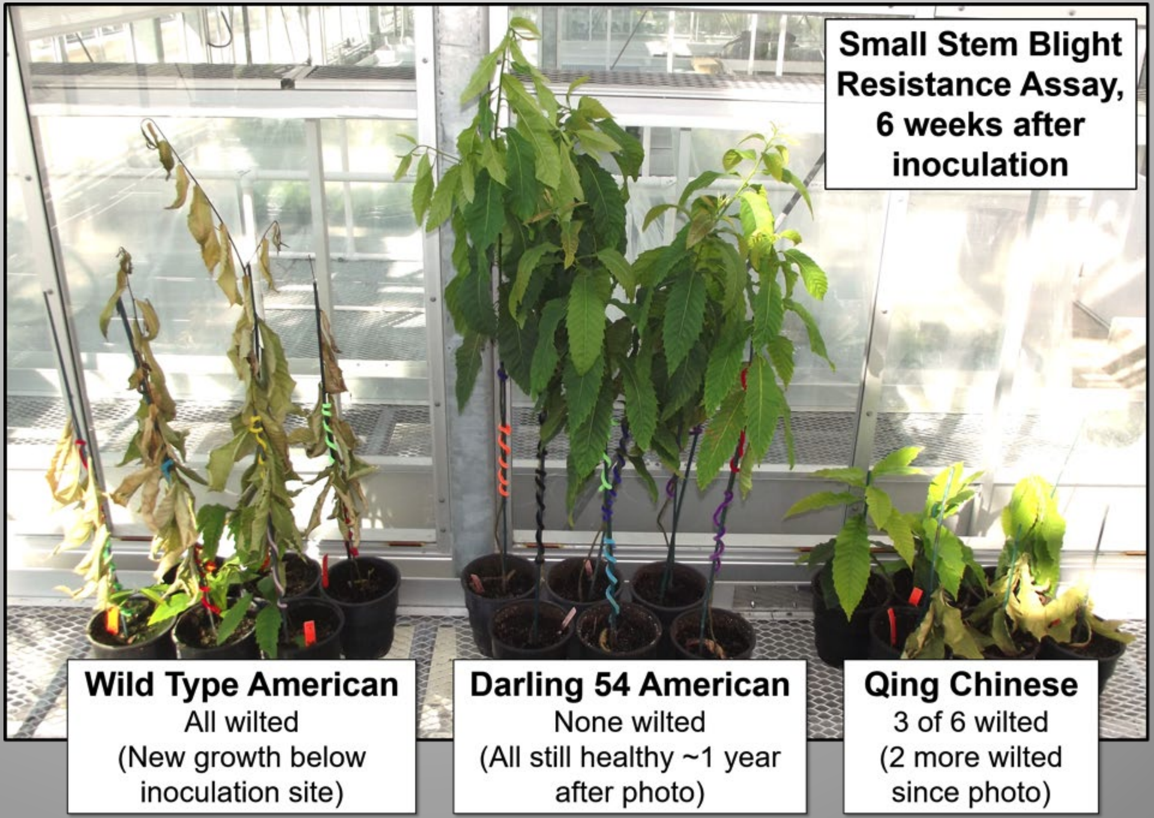
Transgenic insertion of the oxalate oxidase gene (OxO) from wheat enhances blight resistance

Bill Powell
SUNY-ESF

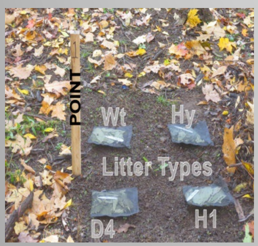
Detoxifies oxalate (oxalic acid)



A ubiquitous, non-gluten, enzyme from wheat
also found in: banana, rice, barley, sorghum, strawberry, date palm, beet, cacao, peanut, peach, apricot, and many more…



Ecological studies of transgenic American chestnut for regulatory review well underway



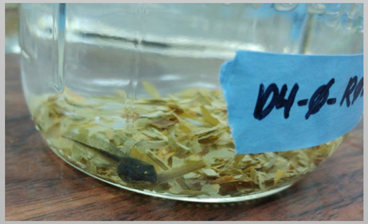
Leaf litter decomposition

Germination of seedlings from chestnut leaf litter

Herbivory on leaves

Colonization of mycorrhizal fungi on roots

Bee feeding on pollen

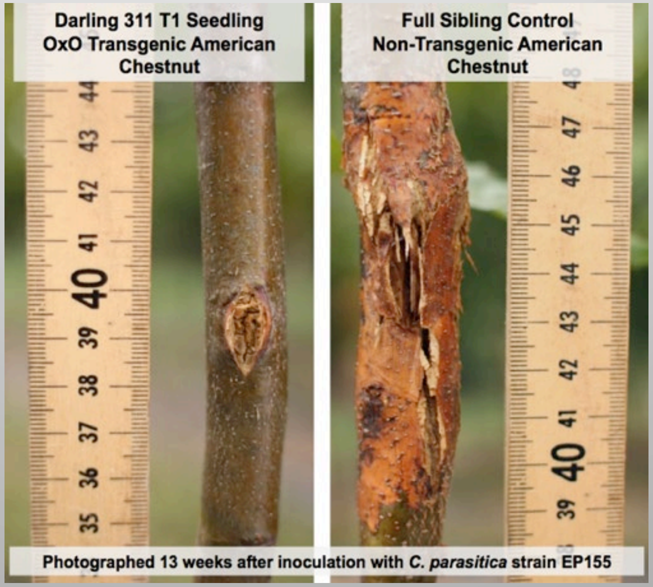


Tadpole development after feeding on leaves

Outcrossing transgenic blight-tolerant American chestnut an efficient method to rescue genetic diversity

ESF

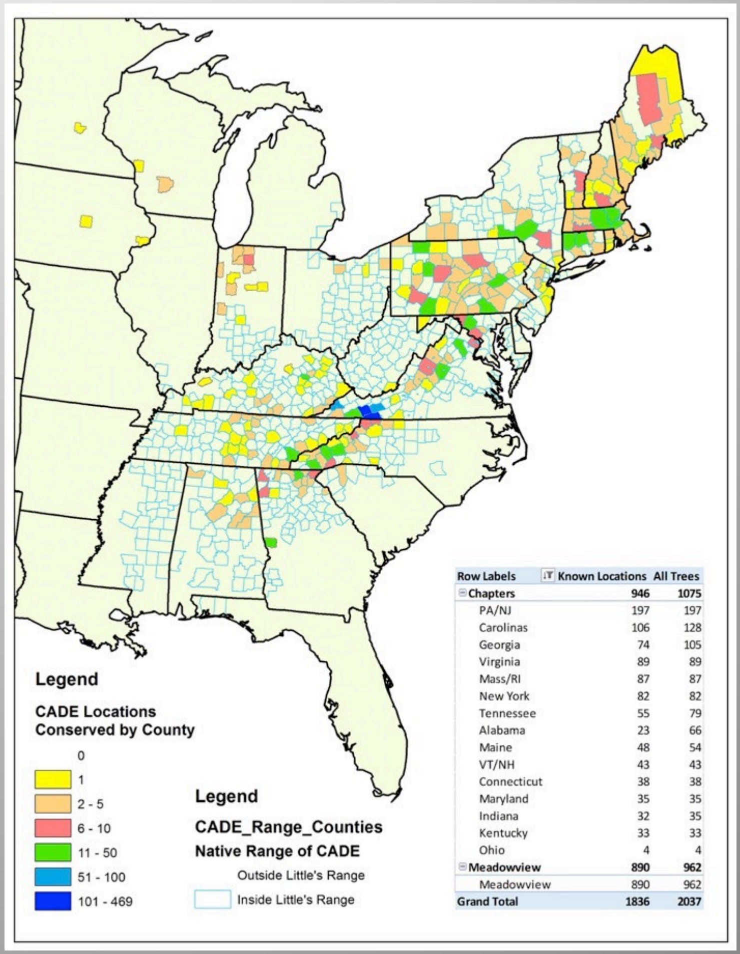
Apply transgenic-OxO pollen to wild-type trees



50% of progeny expected to inherit OxO

Grow plants under high light to induce early flowering = *speed breeding* (for a forest tree!)

Breeding OXO progeny with backcross hybrids may broaden diversity for resistance and adaptation



Row Labels	Known Locations	All Trees
Chapters	**946**	**1075**
PA/NJ	197	197
Carolinas	106	128
Georgia	74	105
Virginia	89	89
Mass/RI	87	87
New York	82	82
Tennessee	55	79
Alabama	23	66
Maine	48	54
VT/NH	43	43
Connecticut	38	38
Maryland	35	35
Indiana	32	35
Kentucky	33	33
Ohio	4	4
Meadowview	**890**	**962**
Meadowview	890	962
Grand Total	**1836**	**2037**

Genomic selection to help select best progeny for crossing and testing

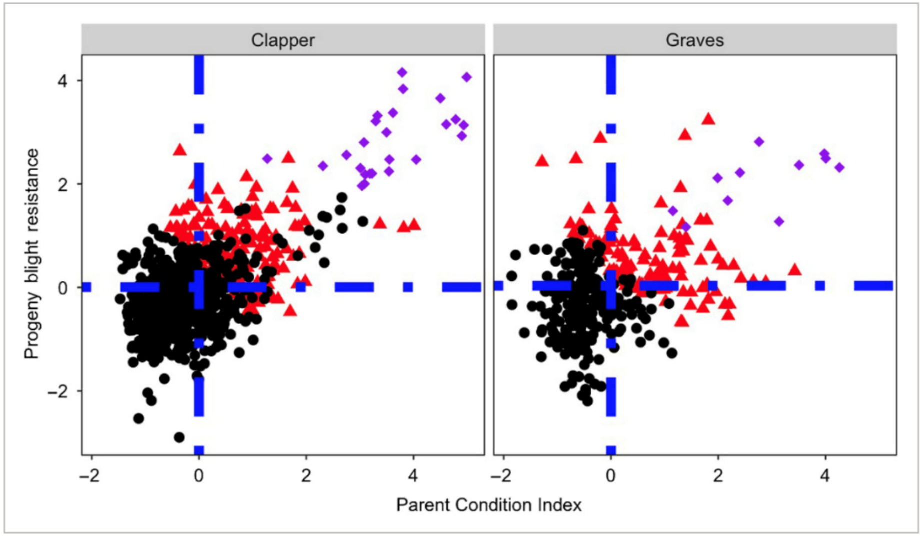


Figure 7 Open in figure viewer | PowerPoint

Relationship between Parent Condition Index and Progeny Blight Resistance for "Clapper" and "Graves" populations. Red triangles are BC_3F_2 selections with up to three selections per seed orchard plot, purple diamonds are pseudo-F_1 progeny of BC_3 trees outcrossed to *Castanea mollissima*, and black dots are inferior trees to cull. Blue dashed lines are the population means for Parent Condition Index and Progeny Blight Resistance

Jason Holliday
Virginia Tech

https://onlinelibrary.wiley.com/doi/full/10.1111/eva.12886

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What are the prospects going forward?

- Are the two cases the tip of the iceberg of biotech innovations relevant to forests and climate?
- Or are they aberrations that tell little about the overall promise of biotech for carbon sequestration and forests?

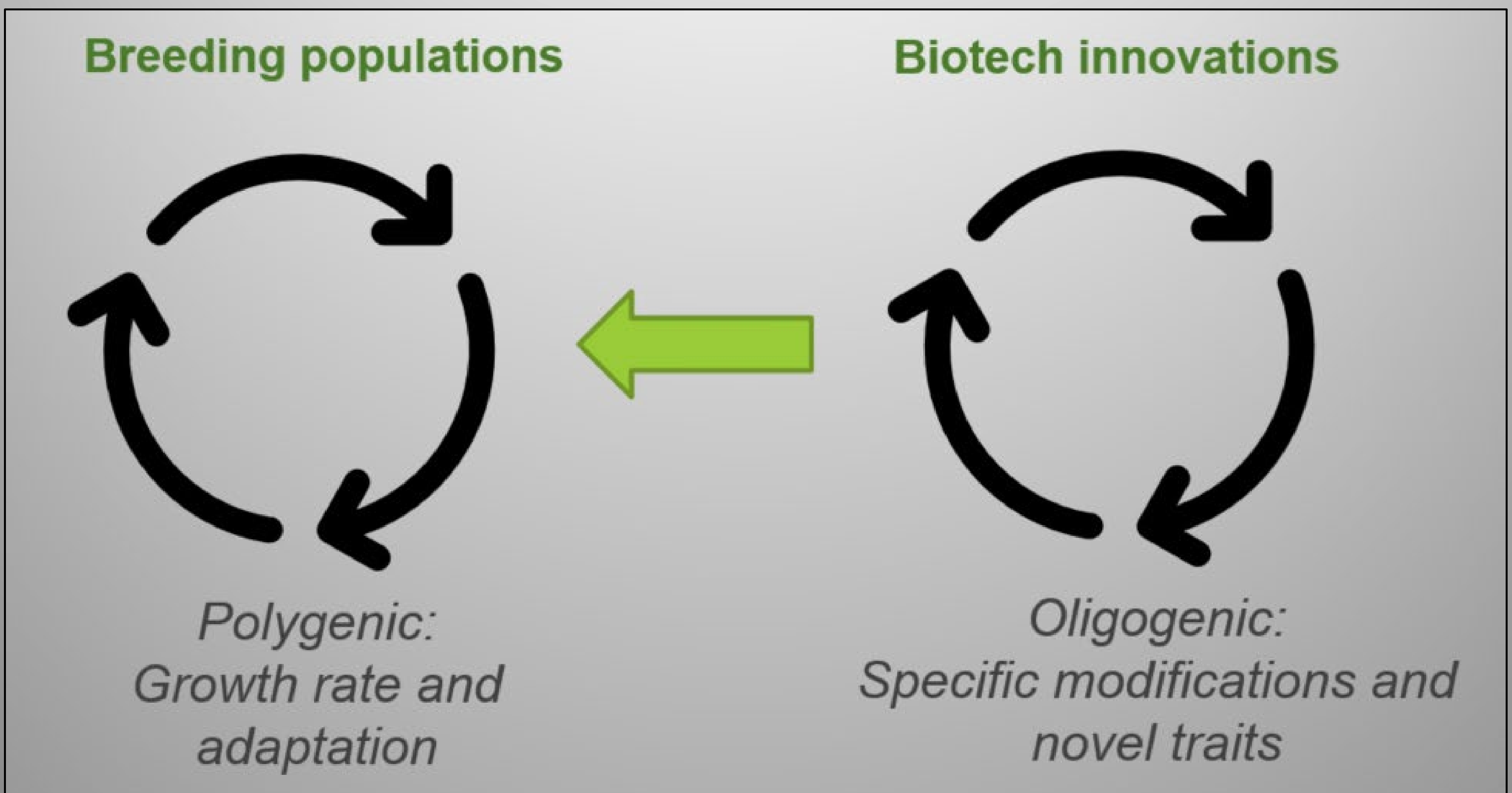
Prospects – Photosynthesis-modified trees

- Too early for results from poplar field trial
- Many innovations that improve greenhouse productivity fail, or disappoint, in the field
- Why? Many stresses in field, complex physiological responses, high environmental variation
- Responses in different tree species, genotypes, and environments likely to be wildly different
- So even if it works, MUCH more work to see if it is truly a general method for enhancement of productivity, let alone other constraints

Carbon sequestration/climate adaptation is much larger than the efficiency of photosynthesis

- Net carbon impacts depend on many factors beyond carbon uptake rate of trees
- Changes to land use from management
- Silviculture operations: Planting, fertilizer, irrigation, thinning, pest control
- Harvest methods, transport, processing into useful products
- Product lifespan

But considering the trees alone, it may be a long time before this happens – vs. invest more in conventional and genomic breeding, vs. other investments



Prospects – blight resistant chestnut

- Regulatory: EPA treats the OXO gene as a pesticide with all the attendant bureaucracy – hope for an exemption, still waiting.
  - And the other genes we will need….?
- Restoration of chestnut is a generational problem – requiring centuries to millenia
- Will the OXO gene hold-up in the field over decades and centuries?
- Will climate change and other diseases wipe out the transgenic trees – need many more (trans)genes?
  - Already a serious exotic pathogen limits use in the southern part of the range
- Is this and the photorespiration cases encouraging re. the use of biotech for mitigating climate stresses on climate and forests?

My answer is – *probably not*

- Only two ~serious cases of biotech forest trees being developed for commercial use in the USA -- and little more elsewhere
- Slow pace of innovation compared to pace of change due to climate emergency
- Inadequate long-term investment in science and technology directed at biotech innovations
- Large market obstacles to use for field studies or commercial plantations
- Outdated, bureaucratic, regulatory stranglehold prevents most translational, field research
- Public confusion over if biotech solutions are welcome or not

"Green certification" creates severe barriers to field research, markets for GMO and gene edited trees

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

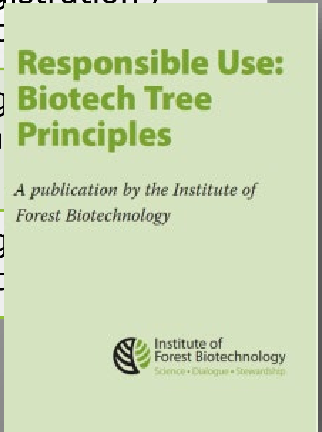
~500 million hectares, ~13% global forest area

FSC

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

All major forest certification systems banned GE trees over time – no exemptions

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 and 2015, forest genetic and biotech scientists publicly criticized FSC for their complete ban on GMOs and gene edited trees

Plantation Certification & Genetic Engineering

FSC's Ban on Research Is Counterproductive

Steven H. Strauss, Malcolm M. Campbell, Simon N. Pryor, Peter Coventry, and Jeff Burley

Genetic engineering, also called genetic modification (GM), is the isolation, recombinant mod-

Plantations can relieve pressure on nat-

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

A new strategy in 2019: A petition to certifiers to allow field research

Petition in Support of Forest Biotechnology Research

Petition | Committee of Scientists | Examples of Biotech Trees | Background Literature | FAQ | Pubs-Press

Drone image of an rDNA-modified poplar plantation in the USA

The goal of this petition is to urge forest certification systems to better align their certification criteria with scientific findings in biotechnology.

http://biotechtrees.forestry.oregonstate.edu

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.

Petition published in Science (September 2019)

Certification for gene-edited forests

Forest certification bodies were estab-
lished 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
pests 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 published in Science

The result of this and industry pressure has been the slightest, slowest movement toward opening up for any uses at all

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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

Regulations that presume guilt for all recombinant DNA modifications make most research untenable, too costly and risky

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

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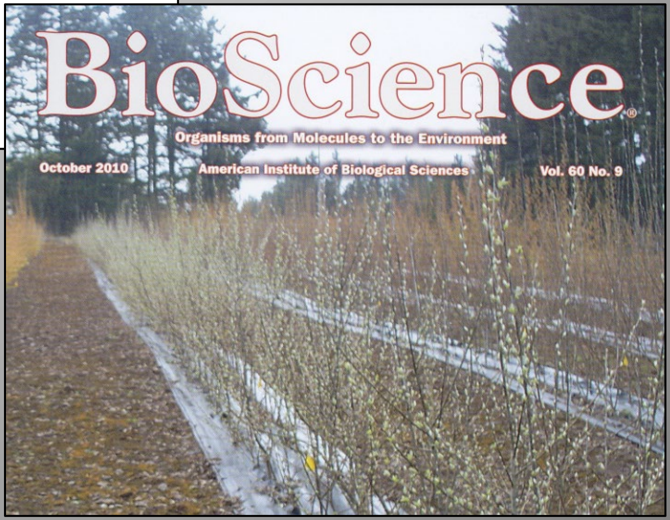
USDA › MEDIA › PRESS RELEASES › USDA SECURE RULE PAVES WAY FOR AGRICULTURAL INNOVATION

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



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||

Organizing Committee for the International Conference on Recombinant DNA Molecules, Assembly of Life Sciences, National Res
Council, National Academy of Sciences, Washington, D.C. 20418. † Chairman of the committee and Professor of Biochemistry,
Department of Biochemistry, Stanford University Medical Center, Stanford, California; ‡ American Cancer Society Professor of M
biology, Center for Cancer Research, Massachusetts Institute of Technology, Cambridge, Mass.; § Member, Scientific Staff of the M
Research Council of the United Kingdom, Cambridge, England; ¶ Professor of Microbiology and Molecular Genetics, Harvard Me
School, and Assistant Bact
Enzymology Section, Labo

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

Summing up

- There are many biotech innovations that may help to grow trees and cope with climate stresses, but most are not being studied beyond the laboratory-greenhouse
- Regulatory constraints limit the ability to incorporate them into nimble and fast-moving breeding programs on pace with climate change
- Market obstacles as well as regulations make companies, and public sector, very hesitant to invest in needed technology
- Whatever the outcome of our poplar field trials of photosynthesis-modified trees, the road beyond is daunting, and workable solutions difficult to imagine