State of the Science

Goals, benefits and safety of genetically engineered (GE) forest trees

Recap of main points from lecture at
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Forest trees differ from annual and perennial herbaceous crops in many ways that require distinct regulatory consideration. I considered these differences from three perspectives, 1) forestry systems, 2) general GE technology, and 3) GE tree studies, as outlined below.

Forestry/forest tree systems

1. **The focus of this paper is on GE trees used for wood products.** Wild and amenity trees, including shade and bioremediation trees, are excluded from consideration.
2. **Forestry systems vary widely, and GE is expected to be used primarily in the most intensive, agronomic like systems in the near future.** Regulations should not consider wild trees or wild forests as the context for GE trees. Poplar and loblolly pine tree-farms (plantations) are examples of the intensive systems in which GE trees may find a place in the near future. Ecological effects of GE trees should be considered in the context of the very large ecological alterations from wild forests already inherent to these intensive systems, including the use of short rotations, intensive weed control, fertilization, highly selected tree varieties, and exotic species.
3. **Gene flow from highly bred and wild forest trees is extensive and familiar, and provides a large buffer for GE gametes.** The long-distance gene flow from trees to wild and cultivated relatives makes possible long distance transgene movement, but also provides a huge dilution to releases of GE pollen and seeds. Because of limited planting area and reproduction of GE trees compared to wild and non-transgenic plantation sources, commercial uses of GE trees may never be so great as to significantly influence gene frequencies in most regions. In some cases, APHIS could permit GE trees only in specific counties to help insure that a large non-transgenic gamete pool exists well into the future, until further studies are completed.
4. **Research and commercial phases overlap extensively in forestry, suggesting that APHIS may need to issue conditional deregulations for trees.** Because of the long lifespan of forest trees, research on new varieties and management methods necessarily continues during early commercial applications. New knowledge is then used to adjust ongoing planting and silviculture (e.g., by

elimination of some varieties that do not perform as expected), a practice commonly called “adaptive management.” APHIS may therefore need to devise a system to permit extensive commercial uses (e.g., via conditional deregulation) while final data is gathered and submitted.

5. **Research is costly due to the long life span, large size, diverse environments, and diverse genotypes used in forestry. Excessive regulatory requirements not called for by tangible biological risks must be carefully avoided, and should consider the opportunity costs they impose for environmental and economic benefits.** This includes avoidance of: regulations that require: 1) detailed data on general tree health that is of obvious industrial self-interest, 2) long-term trials that go beyond what is traditionally required in forest tree breeding (often as few as 2-6 years depending on species), 3) information on specific events vs. kinds of transgenes, and 4) requirements for high levels of confinement not mandated by a high level of risk from specific kinds of transgenes (such as those that may elevate fitness).

<u>General scientific lessons relevant to GE trees</u>

6. **Product not process is what is scientifically relevant: Three National Academy of Science reports have confirmed that there is no scientific basis for regulatory data requirements that apply similarly to all GE species or all GE genes.** APHIS should therefore consider distinctly different data requirements and levels of confinement (if any) for traits such as domesticated wood (e.g., modified lignin) which is highly likely to reduce tree fitness in the wild and thus not promote spread over wild trees, from that of novel genes such as exotic pest resistance proteins.
7. **The mutagenesis caused by the GE process, and general pleiotropy (other changes in phenotype), are familiar to breeders and do not require regulation.** Because trees and other crops can be extensively mutagenized by many methods without regulation with no evidence of significant environmental harm, there is no rationale for applying strict regulations for GE trees apart from effects tied directly to transgene action. Regulations should focus on kinds of transgene: species combinations, not events, as events mainly differ in level of transgene expression and background mutagenesis, and do not raise qualitatively different biological risks. Unintended changes in tree traits associated with the GE process (somaclonal variation and pleiotropy) should also be *encouraged* to be taken advantage of, not penalized, as this is simply an extension of normal breeding—which proceeds by producing large amounts of weakly directed diversity, then selecting within it.
8. **The Bt insect toxin gene, which may raise tree fitness (even if temporarily), is a very special kind of transgene and should not serve as a template for regulations.** The Bt gene is the only gene demonstrated to be effective in field trials whose function and novelty suggest it may impart a fitness benefit to wild trees and thus spread significantly, possibly with negative influences on non-target species. It may therefore require more intensive ecological studies, and intensive genetic confinement mechanisms, compared to other genes under consideration.

Experience from experimental studies with GE trees

9. **GE technology gives high levels of stable transgene expression and low levels of somaclonal variation.** Based primarily in poplars, which have undergone numerous field trials for many genes, genotypes, and regions, the levels of instability in transgene expression and phenotype during tree growth and vegetative propagation are well below that of significant concern to breeders (who will selectively eliminate all but one or a few events per transformation experiment). Though other species are less well known, a similar pattern is also emerging in other species such as pine.
10. **Field studies have suggested that "traditional" transgenes such as herbicide resistance may have large environmental and economic benefits.** Field studies have shown that herbicide resistance genes are highly stable and effective in poplars, and increase the efficiency of weed management and tree growth rate. This should increase yield (producing more wood per unit area), and reduces the need for irrigation, fertilization, cultivation, and use of alternative herbicides. Secondary benefits include improved energy efficiency and soil structure/carbon sequestration.
11. **Advanced research is underway to test a variety of methods for gene confinement via diverse transgenic mechanisms.** Constructs have been produced and are being transformed into trees and field tested that, singly or in combination, may give highly effective genetic confinement. These methods should complement silvicultural methods, such as use of border rows, tight spacing, and early harvest, that greatly mitigate gene flow.
12. **A variety of genes for wood chemical modification has been discovered, and could have very large environmental and economic benefits even if employed modestly.** Genes have been demonstrated to modify lignin quality and quantity in transgenic trees, and some short-term field trials have demonstrated normal tree growth despite greatly increased wood pulpability. Even small changes that reduce chemical use in pulp mills and effluent could have large environmental and economic benefits if used on a large scale.
13. **Field trials, especially those that run for long periods and occur in multiple environments, are essential to measure both the effectiveness of the technology and its ecological effects.** Because of their cost and risk, extensive field trials are likely to require some kind of conditional deregulation for industries and public sector researchers to bear their costs and risks. Regulations need to address means for such studies to go forward, including the provision of allowances for low levels of transgene movement into the environment.