GENETICALLY ENGINEERED TREES

THE NEW FRONTIER OF BIOTECHNOLOGY

CENTER FOR FOOD SAFETY

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ABOUT US

THE CENTER FOR FOOD SAFETY (CFS) is a national non-profit organization working to protect human health and the environment by challenging the use of harmful food production technologies and by promoting organic and other forms of sustainable agriculture. CFS uses groundbreaking legal and policy initiatives, market pressure, and grassroots campaigns to protect our food, our farms, and our environment. CFS is the leading organization fighting genetically engineered (GE) crops in the US, and our successful legal challenges and campaigns have halted or curbed numerous GE crops. CFS's US Supreme Court successes include playing an historic role in the landmark US Supreme Court *Massachusetts v. EPA* decision mandating that the EPA regulate greenhouse gases. In addition, in 2010 CFS challenged Monsanto in the US Supreme Court (*Monsanto Co. v. Geertson Seed Farms*), which set key legal precedents. CFS has offices in Washington, DC, San Francisco, CA, and Portland, OR.

GENETICALLY ENGINEERED TREES

THE NEW FRONTIER OF BIOTECHNOLOGY

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EXECUTIVE SUMMARY

Genetically engineered (GE) trees are a new frontier of plant biotechnology. These trees are promoted as the new green solution with claims that they will save native forests, protect wildlife and biodiversity, mitigate climate change, and more. But behind these false promises is a very different reality.

Trees are being genetically engineered for a range of purposes aimed to accelerate large-scale, industrial monoculture tree plantations and increase profits for biotechnology companies as well as paper, biofuel, lumber, and energy industries.

Instead, trees are being genetically engineered for a range of purposes aimed to accelerate large-scale, industrial monoculture tree plantations and increase profits for biotechnology companies as well as paper, biofuel, lumber, and energy industries. Already, tree plantations of eucalyptus, poplar, oil palm, and pine trees are widely planted around the world and have a legacy of extending deforestation, polluting ecosystems, and often violating human rights in local communities.

Poised on the precipice of adopting this novel, unregulated, and untested technology, this report serves as a primer to GE trees and explores the troubling short- and long-term ecological and socioeconomic dangers that transgenic trees pose.

An overarching theme of this report is that, fundamentally, GE trees—and tree plantations—extend and exacerbate an industrial, chemical-centric approach to agriculture that has already polluted soils, waterways, and air; diminished biodiversity; and emitted greenhouse gases. As with GE crops, monoculture GE tree plantations will require repeated and widespread dousing of chemicals to eliminate pests and plant diseases. But, eventually, these pests and plant pathogens become resistant to chemicals and require more toxic brews.

The vital functions of forests and the primary drivers of deforestation and forest degradation, with a particular focus on the role of biofuel and biomass production, are discussed in Chapter One. The influence of national and international energy policies is also reviewed.

Chapter Two profiles GE trees, focusing on the current status of research and development, ecological and socioeconomic concerns, and the unique attributes of trees that necessitate particularly stringent and long-term analyses with regard to genetic engineering.

In Chapter Three, we look at "what's past is prologue" and demonstrate how the hazards of GE crops portend potential problems with GE trees. Finally, Chapter Four outlines policy recommendations that urge a precautionary approach before determining if GE trees are a viable, sustainable way forward.

An overarching theme of this report is that, fundamentally, GE trees—and tree plantations—extend and exacerbate an industrial, chemical-centric approach to agriculture that has already polluted soils, waterways, and air; diminished biodiversity; and emitted greenhouse gases.

CURRENT STATE OF PLAY

Currently, there are five GE trees approved for commercial planting: virus-resistant papaya and plum in the US, another variety of virus-resistant papaya in China, and two species of poplar engineered for insect resistance in China. The GE papaya in the US is grown on around one thousand acres in Hawaii,[1] and the GE plum has yet to be planted on a commercial scale.

In China, a European black poplar engineered with an insecticide derived from *Bacillus thuringiensis* (Bt) is widely grown, with more than one million trees planted on hundreds of hectares as of 2003.[2] Another insect-resistant poplar was also approved for commercialization in China—a hybrid between white poplar and two Chinese poplar species—and is engineered with Bt and a novel insecticide, API, from arrowhead lily.[3] There are no reliable reports of how many of these GE white poplar hybrid trees have been planted. China also has commercialized a virus-resistant papaya, similar to the Hawaiian varieties. This papaya is thought to be widely planted in China, but there are no reliable estimates of acreage planted.[4] Both Hawaiian and Chinese virus-resistant papaya trees are approved to grow commercially and are being grown in Hong Kong as well.[5]

There are hundreds of field trials with dozens of GE tree species around the world.[6] In the US, trees in the genus *Populus*, such as poplars, aspens, and cottonwoods are the most common experimental GE forest trees, along with species of pines and other conifers, and eucalyptus.[7] Field trials of GE citrus and apples trees are also underway, along with a small field trial of GE banana trees. Currently, there are over 1,000 acres of GE tree field trials in 20 states.

In 2010, the US Department of Agriculture (USDA) approved a widespread planting of experimental GE eucalyptus trees, covering 28 open-air test sites across seven southern states totaling 330 acres. These field trials, planted by ArborGen, the largest tree biotechnology company in the US, consisted of at least a quarter million GE eucalyptus trees. (The Center for Food Safety filed a lawsuit challenging these field trials.)

Simply put, GE trees and tree plantations are no substitute for the myriad complex functions of a forest.

Based on these field trials, ArborGen, a joint venture of MeadWestvaco Corp and New Zealand's Rubicon Ltd, requested permission from the USDA in 2011 to allow commercial plantings of its freeze-tolerant eucalyptus (FTE). If permitted, the GE eucalyptus will be the first transgenic forest tree approved for unrestricted cultivation and will most likely pave the path for speedy clearance of other GE tree species.

PARADISE LOST

Simply put, GE trees and tree plantations are no substitute for the myriad complex functions of a forest. The rich diversity of forests provides an array of ecological services such as building healthy soils; providing habitat for numerous creatures; performing critical hydrological functions; purifying air and storing carbon; and many other features.

Forests harbor a remarkable 70 percent of the world's animal and plant diversity.[8] Forests play a particular role in addressing today's simultaneous environmental crises. As one example, forests are essential in regulating climate change. Forests are reservoirs of soil, biomass, and trees and plants that absorb carbon dioxide (CO_2), a major greenhouse gas, and they also store carbon for many years. According to the United Nations Food and Agriculture Organization (FAO), today's forests have the potential to sequester about one-tenth of global carbon emissions projected for the first half of the 21st century.[9] However, if forests continue to disappear and deteriorate at present rates of 5.2 million hectares per year,[10] we will release even more CO_2 while simultaneously squandering the ability to mitigate climate change through carbon sequestration in forests.

Another central ecological and social predicament of our time is the imminent scarcity of fresh water. Forests are vital to preserving water systems—one-fifth of the world's fresh water is found in the Amazon Basin alone.[11] Given that by 2025 almost 1.8 billion people will be living in regions with absolute water scarcity and two-thirds of the population could be living under water-stressed conditions, forest health is paramount.[12]

Forests also provide 1.6 billion people with shelter, food, water, and other essential daily needs.[13] For example, over 50 million people in India depend on forests for direct subsistence.[14] In West Africa, wild "bushmeat" from the forest provides an important source of protein for both rural and urban households.[15]

Additionally, forests harbor an incredible collection of plants that are critical to modern and traditional medicine. In the US, at least half of the most prescribed medicines come from natural sources found in forests,[16] and 70 percent of all new drugs introduced in the past 25 years have derived from forest plants, animals, and microbial material.[17] For example, a compound from a tropical legume (*Mucuna deeringiana*) is used to treat Parkinson's disease. Forests are also critical for traditional and herbal remedies. Over 5,000 plants are vital for traditional Chinese medicine.[18] The extraordinary treasures contained in forests have barely been tapped. Less than 1 percent of tropical trees and plants have been tested by scientists, who believe that many new compounds with medicinal properties are yet to be discovered.[19]

As naturalist John Muir reminds us: "The clearest way to the universe is through a forest wilderness."[20] Ultimately, a true forest is a wonderful, magnificent wild of the known and unknown that cannot be cultivated and cannot be replaced. To lose these ancient sanctuaries that formed over millions of years is to lose a fundamental life source.

Yet, deforestation and forest degradation are occurring at astonishing rates. The majority of deforestation has occurred in the last two centuries;[21] nearly half of the world's virgin forests have been lost in the last 50 years.[22] In addition to deforestation, forest health is declining due to industrial activities such as road construction, mining, water diversion projects, and a host of other such activities. This further disrupts biodiversity, wildlife habitat, soils and microbes, and other attributes necessary for planetary survival.

DRIVERS OF FOREST DEMISE

Our legacy of deforestation has profound implications for societies and for our future. Understanding the drivers of forest destruction is critical in order to construct viable, comprehensive solutions. What activities are leading to forest demise? What regions of the world are most affected? Do GE trees have a place in our vision of a sustainable future?

Our legacy of deforestation has profound implications for societies and for our future. Understanding the drivers of forest destruction is critical in order to construct viable, comprehensive solutions.

Historical trends of degradation vary according to geography, economies, and politics. In the US, deforestation largely happened prior to the 20th century with the arrival of European settlers.[23] Between 1990 and 2000, countries with the largest losses of forest area include Brazil, Indonesia, Sudan, Zambia, Mexico, and the Democratic Republic of the Congo.[24] Forest destruction occurs in these countries for a variety of reasons. For instance, in Brazil, soybean crops for biofuels are displacing cattle ranches. Perversely, more forests are then cut down to provide land for cattle.

As forester Aldo Leopold wrote: "Wilderness is the raw material out of which man has hammered the artifact called civilization."[25] These words sum up the essential driver of deforestation—the insatiable desire of industrial societies for energy and accoutrements of 21st century lifestyles. Specific causes of deforestation are numerous and complex. Most researchers agree that primary drivers of deforestation are extractive industries for lumber, wood-related products, and minerals such as clay; large-scale cattle ranching; and industrial, monoculture agriculture—both for food and fuel.

Some point to growing populations in developing countries as a major contributor to forest degradation; however, it is the most intensely industrialized countries that consume an overwhelming majority of forest and wood products. Comprising just 16 percent of the global population, North American, Japanese, and European consumers use around two-thirds of the world's paper and paperboard and half of its industrial wood.[26] Consumption of meat and biofuels is also much higher in these regions than in developing nations.[27]

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LOSING THE FORESTS FOR THE TREES

"It's through plantation forests and increased productivity that you protect native forests,"[28] maintains Barbara Wells, former CEO of ArborGen and former executive at Monsanto. Forest destruction in Indonesia detailed in this report debunks this theory and uncovers the full scope of negative consequences of tree plantations. Astonishingly, Indonesia has lost over half of its forests since the 1960s, primarily because of oil palm tree plantations.[29] Palm oil derived from oil palm trees, used largely for processed foods, biofuels, and personal care products, is a burgeoning commodity. As demand for palm oil increases, oil palm tree plantations expand and encroach into forests. Along with this, several species, including the orangutan and Sumatran tiger, are now endangered in Indonesia due to loss of habitat.[30]

Life-threatening smog due to regular and deliberate fires set by palm oil companies to clear fields and forests for more plantations is yet another consequence. Recent news stories document the widespread smog affecting local inhabitants and neighboring countries. Malaysia declared a state of emergency due to rising air pollution levels, and Singapore urged people to remain indoors because of "hazardous" levels of pollution.[31]

Additionally, tree plantations are frequently associated with "land grabs" whereby richer, industrial countries purchase land in developing countries to grow crops for biofuels and other ventures. These land grabs by corporations or foreign governments often devastate local populations that have lived in these regions for generations, often with no formal claim to the land. While foreign investors promise jobs, food, and economic development, too frequently communities are left without livelihoods, food, or water, and are marginalized with little recourse.

Genetically engineered tree advocates consistently claim that tree plantations are a sustainable way to save forests, yet Indonesia's experience with land grabs reflects a growing trend of expanding tree plantations at the expense of forests and local populations. For example, in the Lumaco district of Chile, pine and eucalyptus plantations have expanded from 14 percent of land in 1988 to 52 percent in 2002, clearing forests and displacing local communities.[32]

The continued expansion of tree plantations illustrates the basic principle that supply and demand do not remain static. For instance, a Brazilian forest-asset company claims that the eucalyptus tree market has potential to expand by 500 percent over the next 20 years.[33] Economic imperatives ensure that more land will be cleared for tree plantations as demand increases for wood-based products.

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National and International Energy Policies

As this report examines, national and international energy policies significantly encourage technologies such as GE trees. In the US, the Renewable Fuel Standard (RFS) program, part of the Energy Policy Act of 2005, sets mandates for production of corn ethanol and other biofuels. To spur biofuel development, policies prescribe a variety of federal, state, and local incentives such as tax credits and exemptions, grants, and loan guarantees. As a result, corn production used for biofuels increased from 1.168 to 4.900 billion bushels in the last decade.[34] US farmers increased the number of acres planted in corn from 80 million in 2000-2001 to 88 million in 2010-2011.[35] Such increased cultivation comes at the expense of former Conservation Reserve Program lands and other pristine areas.[36]

In order to meet mandates that steadily increase,[37] industry is looking to produce biofuels from cellulosic ethanol derived from trees or other woody plants, particularly poplar trees. Genetically altering or reducing lignin content, a structural component of wood, makes it easier to break down woody biomass and access sugars for ethanol production. However, lignin is an important component of trees. For example, lignin maintains the structural integrity of trees and helps to repel pests while also playing a central role in decomposition, which nourishes soils.[38] Reducing lignin in GE trees raises the additional concern that non-GE and wild trees may become structurally weaker if contaminated.

Biotechnology and many energy corporations promote GE trees, and the particular trait of reducing or altering lignin content, as a climate change mitigation measure;

however, research does not support this claim. For instance, aspen trees with altered lignin store 30 percent less total plant carbon than non-GE aspens.[39]

In both the US and Europe, renewable energy mandates, in tandem with climate change mitigation measures, have also led to an increasing demand for biomass sources such as wood pellets. Large utility and energy corporations view fast-growing, as well as low-lignin, GE trees as a way to meet high demand. The pellets are typically burned in combination with coal, oil, or natural gas to power plants that generate electricity. However, emerging science reveals that burning trees and/or wood pellets produces high rates of greenhouse gas emissions and other pollutants and is not a sustainable solution to replace fossil fuels or coal.[40] Nevertheless, at least 30 wood pellet production facilities are operating or in development across the southern US,[41] and hundreds of new "renewable energy" facilities have been developed to burn wood pellets as a result of government support for wood products as an alternative fuel.[42]

Additionally, the US is now the world's largest exporter of wood pellets,[43] with most shipments transported from ports in the southeastern US to the EU where companies are seeking to comply with sulfur dioxide restrictions. Wood pellets are typically co-fired with coal to fuel power plants.[44] However, studies show that while wood pellet biomass does lower sulfur dioxide emissions, it increases a variety of other emissions and ultimately prolongs the life of these polluting power plants, all under the guise of climate-friendly energy production.[45]

ArborGen's freeze-tolerant eucalyptus tree, currently awaiting approval for commercialization, will enable eucalyptus trees to grow in colder climates of southeastern states and bolster wood pellet production for use both in the US and the EU.

In addition to discussing how domestic energy policies link to GE trees, the report provides examples of how international institutions and initiatives can also stimulate genetic engineering and plantation forestry. For example, the Clean Development Mechanism (CDM), an emissions reduction credit program that is part of the Kyoto Protocol, enables corporations to obtain saleable carbon credits for tree plantations. Critics of the CDM assert that this carbon credit scheme simply allows bad environmental practices to continue and even expand. To illustrate, Sierra Gold Corporation, a Canadian mining company operating in Sierra Leone, plans to use revenue from its 45,527 hectare Kiri tree plantation, valued at $715 million over 50 years, to expand mining operations in West Africa.[46]

Threatening Food Security

This report highlights the little discussed link between biofuel policies and increased hunger. With 40 percent of US corn now destined for biofuel production, corn commodity prices have surged.[47] For example, in 2009-2010, developing countries that were net-importers of corn paid 21 percent more for a bushel of corn.[48] This has led to food scarcity in some developing countries. A United Nations report concludes:

In the same way that Monsanto and other agribusiness giants transformed the landscape of agriculture with GE crops, ArborGen and other tree biotechnology companies have a vision of a forest products industry dominated by plantations stocked with their proprietary GE trees.

"prices [of food commodities] are substantially higher than they would be if no biofuels were produced."[49] Using GE trees to further expand tree plantations will almost certainly intensify global food crises as land once grown for food is shifted to production for biofuels.

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GE TREE PROFILES AND OVERVIEW OF POTENTIAL ECOLOGICAL IMPACTS

In the same way that Monsanto and other agribusiness giants transformed the landscape of agriculture with GE crops, ArborGen and other tree biotechnology companies have a vision of a forest products industry dominated by plantations stocked with their proprietary GE trees. ArborGen has projected its profits will boost yearly sales from $25 million to $500 million in 2017 if GE trees are commercialized.[50]

Genetically engineered forest trees such as pines, poplars, and eucalyptus would be used for traditional lumber and paper products and serve as raw material for biomass such as wood pellets, cellulosic ethanol, and fuels such as terpene extracted from pine trees. A nascent segment of the GE tree industry is developing fruit and nut trees with novel disease and pest resistance as well as altered ripening or storage characteristics.

Industry markets GE trees as being solutions to a host of environmental problems. The GE American chestnut is showcased as way to restore this lost "heritage tree"; other GE trees are promoted as being "climate-friendly." However, such pronouncements are often aimed to capture the hearts and minds of the public and obscure controversial endeavors that can result in serious ecological consequences.

In profiling GE trees and examining potential impacts on forests and wild trees and plants, the report highlights special attributes of trees and how they are more complex than agricultural crops. As one example, trees can reproduce over long distances via wind, water, and wildlife. The eastern cottonwood can produce almost 30 million wind-dispersed seeds in one season,[51] and some pine pollen can travel more than 25 miles and still be viable.[52] This presents significant concerns about transgenic contamination of non-GE trees and wild relatives, and more broadly, the health of forests.

For the GE eucalyptus, ArborGen claims to have minimized potential contamination by inhibiting pollination. However, the genetic alteration causes only male sterility, allowing for potential pollination between GE flowers and conventional, non-sterile eucalyptus.

These issues and more are discussed in Chapter 2 and demonstrate why it is essential to pursue a precautionary path and conduct long-term, comprehensive studies before determining if a GE tree should be cultivated.

In addition, this section of the report provides a vignette on how the development of GE trees, such as the GE American chestnut, can provide cover for polluting industries. Duke Energy, the largest electric power holding company in the US with major surface coal mining operations, is financing GE American chestnut development to stock tree plantations harvested for its wood pellet mills.

In both the US and Europe, renewable energy mandates, in tandem with climate change mitigation measures, have also led to an increasing demand for biomass sources such as wood pellets.

Paradoxically, Duke Energy views GE American chestnuts as being "highly effective carbon-sequestering machines,"[53] and, together with the Forest Health Initiative, plans to repopulate the company's coal mountain top removal sites with the trees. Not mentioned in the marketing of this highly touted project is that US federal law requires coal-mining industries to restore abandoned mine lands by 2015.[54]

PAST IS PROLOGUE

When assessing the potential impacts of transgenic trees, we can learn from the scientific and empirical experience of GE crops. As an early adopter and the largest cultivator of GE crops, the US experience portends potential environmental and socioeconomic consequences of GE trees. Chapter Three enumerates how GE crops have increased use of chemicals, contaminated conventional and organic crops with transgenes, created "superweeds," and more. As with GE crops, transgenic trees will potentially exacerbate the problems they purport to solve, and create new, often unintended, consequences.

POLICY RECOMMENDATIONS FOR A SUSTAINABLE FOREST FUTURE

Significant uncertainties and a wide range of ecological impacts of GE trees require diligent, immediate engagement of civil society, governments, the media, and the general public. Current laws and regulatory frameworks are outdated and woefully inadequate in regard to genetic engineering writ large. A predominant theme of this report is to encourage new legislation that emphasizes a precautionary regulatory framework for GE organism regulation and GE tree regulation specifically. A model law could draw on the approach of the EU, which has more stringent and long-term analyses of potential effects of this life-altering technology. Strategies to address national and international policies and arenas impacting biotechnology, particularly GE trees, are also discussed.

* * *

Clearly, as demand for energy and wood-based products continues to expand, societies must craft solutions that revitalize and maintain the integrity of forests and wild creatures while also ensuring equitable distribution of essential needs for all communities. There are many approaches and paths that can be pursued—conservation; traditional plant and tree breeding; and reduction of energy, consumer goods, and paper product consumption; to name only a few measures. Solutions must be smart and also systemic, perhaps requiring a radical review of assumptions. Developing holistic assessments is essential.

This report suggests that GE trees and plantations are not a visionary, sustainable way forward, and instead will lead to myriad, widespread harm to nature and societies.

Ultimately, a true forest is a wonderful, magnificent wild of the known and unknown that cannot be cultivated and cannot be replaced. To lose these ancient sanctuaries that formed over millions of years is to lose a fundamental life source.

CHAPTER ONE

PARADISE LOST— FUNCTIONS OF FORESTS AND DRIVERS OF DESTRUCTION

> *We need to come, as soon as possible, to a profound understanding and appreciation for trees and forests and the vital role they play, for they are among our best allies in the uncertain future that is unfolding.*
>
> —JIM ROBBINS, *The Man Who Planted Trees: Lost Groves, Champion Trees, and an Urgent Plan to Save the Planet*[1]

Forests are integral ecosystems necessary to all forms of life on our planet. This chapter examines the various facets of forest life and their vital functions as well as reviews the drivers of deforestation and decline of forests. Examining the complex, interconnected web of life contained in forests helps illuminate the deficiencies and dangers of genetically engineered (GE) trees and plantations.

The serious implications of deforestation for life on this planet cannot be overstated. Often referred to as the earth's lungs, forests maintain our atmosphere as well as global climate stability by absorbing and regulating carbon dioxide and producing oxygen. They also contain mysteries still to be discovered—medicinal compounds, beneficial insects, plants, and more. Yet ancient forests that have evolved over millions

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of years are rapidly disappearing and being degraded due to today's insatiable demand for timber, wood-based products, agricultural and pastoral land, and biofuels.

Some claim that GE tree plantations are the solution to global forest destruction. However, upon close examination, it is clear that GE trees cannot replace or mimic the numerous, complex roles of forests. To begin with, tree plantations follow an industrial monoculture model that, like crop monocultures, results in a host of problems, including loss of biodiversity, increasing insect and disease pressure, loss of topsoil, water pollution, and more. Genetically engineered tree plantations exacerbate many of these issues and create new problems, such as the introduction of trees with novel transgenes into native forests. The full scope of harms and vulnerabilities of GE trees are examined in detail in Chapter Two.

The majority of deforestation has occurred in the last two centuries. Nearly half of the world's virgin forests have been lost in the last 50 years.

FUNCTIONS OF FORESTS

Forests provide a wealth of resources and benefits. Forests protect soils; provide habitat for the majority of the planet's species; control water flow and protect hydrological systems; regulate atmospheric gases; engender and preserve plant diversity, including critical medicinal plants; and much more. They also provide paper, timber, medicines, food, and other products. Forests are home to 1.6 billion people, providing shelter, food, water, and other essential daily needs.[2]

The majority of deforestation has occurred in the last two centuries. Nearly half of the world's virgin forests have been lost in the last 50 years.[3] Today, forests cover 31 percent of the earth's land surface, or over 4 billion hectares (one hectare equals 2.47 acres).[4] According to the United Nations Food and Agriculture Organization (FAO), the highest rate of forest depletion occurred in the 1990s, when the world lost an average of 16 million hectares each year.[5] That is roughly the size of the state of Wisconsin.[6]

These astonishing rates of deforestation still do not fully capture the decline of forests around the globe. In addition to deforestation, forest degradation is a major problem. Road construction, logging, and other industrial activities that fragment forests greatly affect biodiversity, wildlife habitat, soils and microbes, and other attributes necessary for planetary survival.

Equally relevant, there are different types of forests, including tropical, temperate, and boreal. Each type of forest contains different ecological attributes; this is important to consider when reviewing strategies for reforestation. Too often, proponents of GE tree plantations view reforestation through the narrow lens of the area of trees planted rather than holistic forest health. For example, trees planted in temperate zones cannot replace the ecological characteristics, such as biodiversity, lost in tropical forests. Thus, strategies proposed by many industrial countries to mitigate climate change by planting trees in temperate areas to replace industrial country-driven destruction of tropical forests is not a legitimate solution to deforestation.

The following sections outline the fundamental roles of forests and summarize the harms of deforestation and forest degradation.

If forests continue to disappear and deteriorate at the present rate of 5.2 million hectares per year, we will release even more carbon dioxide while simultaneously squandering the ability to mitigate climate change through carbon sequestration in forests.

CLIMATE STABILIZATION AND AIR QUALITY

Forests of many types are vital for global carbon cycle functions, including the regulation of the atmospheric concentration of carbon dioxide. Forests are reservoirs of carbon: soil, biomass, and trees absorb carbon dioxide and store carbon for a very long time.[7] When trees are cut down, much of the carbon is released into the atmosphere as heat-trapping carbon dioxide.[8]

Statistics vary, but scientists agree that deforestation is a major contributor to climate change. The Intergovernmental Panel on Climate Change suggests that deforestation and forest degradation account for up to one-third of anthropogenic carbon dioxide emissions.[9] Other studies propose that carbon dioxide emissions due to deforestation range from 6 to 17 percent.[10]

According to the FAO, forests have the potential to sequester roughly one-tenth of the global carbon emissions projected for the first half of the 21st century.[11] However, if forests continue to disappear and deteriorate at the present rate of 5.2 million hectares per year,[12] we will release even more carbon dioxide while simultaneously squandering the ability to mitigate climate change through carbon sequestration in forests.

WATER

Forests are vital to the earth's hydrological cycle and preserving water quality and availability. Already, water scarcity affects around 40 percent of people living on the planet today.[13] By 2025, 1.8 billion people will be living in countries or regions with absolute water scarcity, and two-thirds of the world's population could be living under water-stressed conditions.[14] Forests are key to maintaining fresh water; one-fifth of the world's fresh water is found in the Amazon basin alone.[15]

Forest tree root systems hold soil together; the leaf litter and debris that fall from trees break down and combine with minerals to form complex organic soil layers that function like giant sponges, perfect for collecting water. Simultaneously, forest canopies collect rainwater; water flows through tree leaves and percolates slowly down into the absorbent soil. Deforestation removes these complex root systems and magnificent canopies, which can lead to surface water runoff, soil erosion, and flash floods.

In a process known as transpiration, trees pull groundwater up through their systems and slowly release it into the atmosphere. Transpiration contributes approximately 10 percent of the moisture in the atmosphere, making it a vital process in regulating our climate.[16] As a forest is diminished, less water is released by trees, which can lead to drier microclimates that affect global weather patterns.

A remarkable 70 percent of the world's animal and plant biodiversity is found in forests, predominately the tropical forests that are currently under the most pressure from degradation.

SOIL

Forests also play an integral part in keeping our soils healthy and intact. Trees and other forest vegetation are anchors for soil, holding it in place and allowing it to become nutrient-rich. Deforestation, on the other hand, quickly leads to soil instability. The absence of tree roots and vegetation loosens soil, making areas more prone to flash flooding, erosion, and landslides. The severe runoff has significant impacts downstream, causing sediment buildup that further contributes to flooding and cloudy water. Sediment even reaches coral reefs, causing marine die-offs and major aquatic disturbances.

History provides numerous examples of civilizations that collapsed as their forests disappeared, leaving behind arid land. The fate of the once-flourishing Fertile Crescent of Mesopotamia is illustrative. As cedar forests were cleared, the hydrologic cycle dramatically changed and soil erosion progressed.[17] Rivers in the area flowed with silt and salt from eroding, destabilized soils. Eventually, agricultural soils became saline and unsuitable for growing food and fiber. Similarly, many suggest that a major reason for the decline of the Roman Empire was massive deforestation throughout the Empire, a practice that resulted in desertification, soil erosion, and watershed depletion, leading to dramatic declines in food stocks.[18]

BIODIVERSITY

A remarkable 70 percent of the world's animal and plant biodiversity is found in forests, predominately the tropical forests that are currently under the most pressure from degradation.[19] This biodiversity takes the form not only of distinct plants and animal species, but also important microbes and plant varieties with unique resistances to pests and diseases. Deforestation is rapidly diminishing the biodiversity of our planet. Overall, high rates of species extinction correlate to the loss and decline of forests. It is now estimated that over 1,000 animal species are disappearing annually.[20] Some calculate that 137 species of life forms are driven into extinction every day in tropical rainforests, where roughly half of all animal species make their home.[21] Equally alarming, it is estimated that 5-10 percent of tropical rainforest plant species will be lost per decade in the future.[22]

MEDICINE

Not only are forests home to a vast array of animal species, but they also harbor an incredible collection of plants that are critical to modern medicine. For example, the bark of the African plum tree (*Prunus africana*) is used to treat prostate cancer; a compound from a tropical legume (*Mucuna deeringiana*) is used to treat Parkinson's disease; and the decongestant ephedrine is derived from a Chinese shrub (*Ephedra sinica*). In the US, at least half of the most prescribed medicines come from natural sources found in forests,[23] and 70 percent of all new drugs introduced in the past 25 years have derived from forest plants, animals, and microbial material.[24] Further, according to the US National Cancer Institute, 70 percent of the 3,000 plants used for anti-cancer drugs come from rainforests.[25] Given that less than 1 percent of these tropical trees and plants have been tested by scientists, forests could provide many new compounds with medicinal properties.[26]

Forests provide an essential food source to 1.6 billion people around the globe.

To illustrate the incredible plant diversity contained in tropical forests, Costa Rica, a country of 51,000 square kilometers, contains around 8,000 species of plants. In contrast, Britain, with almost five times the land area, has fewer than 1,500 species.[27] We endanger untapped resources, with species and medicines still to be discovered, when the well-being of forests is threatened.

Plants are equally important for traditional and herbal remedies. In China alone, traditional medicine relies on over 5,000 plants used for treating both urban and, particularly, rural patients.[28] Similarly, Ayurveda, an ancient medical system from the Indian subcontinent, depends on thousands of plants for its medicines and treatments. In some Asian and African countries, approximately 80 percent of the population depends on traditional medicine, based on many forest herbs and plants, for primary health care.[29]

FOOD AND FOREST COMMUNITIES

Forests provide an essential food source to 1.6 billion people around the globe.[30] In parts of India, over 50 million people depend on forests for direct subsistence.[31] In Laos, 80 percent of the population consumes forest-derived foods regularly.[32] For many rural people in West Africa, wild "bushmeat" from the forest provides an important source of meat for both rural and urban households.[33]

By contributing to people's diets and nutrition, often by supplementing agricultural staples, forests play a substantial role in maintaining food security around the world. Forest products provide extra nutrients and add variety and flavor to otherwise nutritionally poor diets.[34] Moreover, forests provide fodder for animals raised for food, providing an extra degree of food security. In times of drought, forest resources become particularly essential to rural and nomadic communities. Converting forest land for other uses such as biofuel or industrial agriculture jeopardizes communities' ability to sustain themselves. (See *Genetically Engineered Trees—Link to Land Grabs*.)

MAJOR DRIVERS OF DEFORESTATION AND THE RISE OF TREE PLANTATIONS

Understanding drivers of deforestation is critical to crafting truly sustainable solutions to restore and maintain forests.

> *What we are doing to the forests of the world is but a mirror reflection of what we are doing to ourselves and to one another.*
> —MAHATMA GANDHI

Deforestation has myriad causes—the majority of deforestation has occurred in the last two centuries, largely due to clearing of land for agriculture, but also for timber for building and fuel.[35] This section explores trends and policies that lead to forest destruction and intensify other environmental harms. What are the major drivers of deforestation and degradation of forests? Which regions of the world are most affected? These are central questions that can help determine collective global actions to save forests and the abundant life in them.

The most intensely industrialized countries account for the majority of the demand for forest and wood products. North American, European, and Japanese consumers, which represent 16 percent of the world's population, use around two-thirds of the world's paper and paperboard and half of its industrial wood.[36]

The specific causes of deforestation are numerous and can be complicated to confirm. However, it is clear that the highest rates of deforestation over a short period of time correlate to industrialization and industrial societies. Most researchers agree that trends of deforestation have been primarily driven by extractive industries for timber, wood-related products, and minerals such as clay; large-scale cattle ranching; and industrial, monoculture agriculture—both for food and fuel.[37] Industrial countries consume more than twice the amount of biofuels as developing countries.[38] And, FAO data show that per capita, industrial countries eat significantly more meat than other countries, though this trend is changing as the western diet gains traction around the globe.[39]

Historical trends of forest degradation vary according to geography, economies, and politics. In the US, major deforestation occurred prior to the 20th century with the arrival of European settlers to the area. Deforestation rates coincided with population growth as forests were cleared for agriculture and fuel.[40] Logging for timber as a major industry began in the late 19th and early 20th centuries. In the last few decades, major drivers of deforestation and forest degradation in the US include paper and pulp production and wood pellet production.[41]

The countries with the largest losses of forest area between 1990 and 2000 include Brazil, Indonesia, Sudan, Zambia, Mexico, and the Democratic Republic of the Congo.[42] Drivers of deforestation in these regions are varied. In Brazil, land is cleared for large industrial crops, such as soy used for biofuel production, and cattle ranches. Palm oil production is the central driver in Indonesia, a country that has lost over half of its forests since the 1960s.[43] (See *Case Study of Oil Palm Plantations in Indonesia*.)

Mining for minerals and terrestrial oil and gas is an emerging driver of deforestation in Central Africa.[44]

Application of synthetic nitrogen fertilizer—on crops and tree plantations—contributes an alarming 60 percent of global nitrous oxide emissions, a gas nearly 300 times more potent than carbon dioxide.

ENERGY AND CLIMATE CHANGE POLICIES

Increasingly, energy mandates and incentives are expanding biofuel production globally. First passed as part of the US Energy Policy Act of 2005, the Renewable Fuel Standard (RFS) program set mandates for the production of corn ethanol and other biofuels in the US. The RFS mandates that 9 billion gallons of biofuel be produced by 2008 with increase biofuel targets for subsequent years.[45] For 2013, almost 10 percent of US transportation fuel is mandated to be derived from biofuels.[46] To incentivize biofuel development, policies prescribe a variety of federal, state, and local incentives, such as tax credits and exemptions, grants, and loan guarantees.[47] As a result, corn production used for biofuels increased from 1.168 to 4.900 billion bushels in the last decade.[48] US farmers increased the number of acres planted in corn from 80 million in 2000-2001 to 88 million in 2010-2011.[49] Such increased cultivation comes at the expense of former Conservation Reserve Program lands and other pristine areas.[50]

Trees genetically engineered to reduce lignin content for easier breakdown of plant sugars and production into cellulosic ethanol are a major part of the biofuel strategy. But rather than provide greener fuels as advertised, GE tree plantations further perpetuate industrial approaches that harm ecosystems. As one example, monoculture tree plantations require massive amounts of chemicals; this pollutes soil, water, and air, destroys habitat, and contributes to greenhouse gas emissions. Application of synthetic nitrogen fertilizer—on crops and tree plantations—contributes an alarming 60 percent of global nitrous oxide emissions, a gas nearly 300 times more potent than carbon dioxide.[51]

The quest to increase biofuel production also results in indirect land use change (ILUC). The following is an example of ILUC: land used for livestock pasture in Brazil is now being shifted to soy grown primarily for biodiesel. Meanwhile, the demand for beef is strong, so more forests are cleared for new livestock pastures, resulting in indirect forest clearing from biofuel expansion.[52] This disturbing trend continues despite the voluntary moratorium by Brazilian soy farmers on clear-cutting primary forests. It is estimated that nearly 60 percent of deforestation occurring in the Amazon between 2003 and 2020 will be due to indirect land use change stemming from biofuel production.[53]

Fueling Food Crises

Biofuel mandates seriously jeopardize food security for many developing nations, a trend that is rarely discussed.[54] Spurred by biofuel policies, the proliferation of "biofuel crops" has dramatically affected global food prices and led to increased hunger. With 40 percent of US corn now destined for biofuel production, corn prices have surged. For example, from 2009-2010, developing countries that were net-importers of corn paid 21 percent more for a bushel of corn due to the rapid expansion of ethanol production.[55] A 2011 report on price volatility in food commodities concluded: "Prices [of food commodities] are substantially higher than they would be if no biofuels were produced."[56]

Similar to US policy, EU goals to increase biofuel production are also harming developing countries. In the EU, the Renewable Energy Directive mandated a 5.75 percent share of biofuels in the transportation sector by 2010. By 2020, the share of transport fuel from renewable energy—including biofuels—is targeted at 10 percent for each member state.[57]

To fulfill their mandates and greenhouse gas reduction goals, European biofuel producers access cheap land in the developing world. In 2010, over 36 percent of all biofuels consumed in the EU was harvested from crops outside the EU.[58] In October 2012, in response to growing concern over this indirect land use change and the "food versus fuel" narrative, the EU proposed limiting the amount of renewable energy sources stemming from biofuels to 5 percent.[59] (See *Genetically Engineered Trees—Link to Land Grabs*.) This has not yet been implemented.[60] As of 2011, 21 other countries have also passed legislation that mandates the production and use of biofuels, such as China and Brazil, both huge exporters of biofuels.[61]

Biomass

Renewable energy mandates have also led to increasing demand for biomass sources such as wood pellets. The pellets are typically burned in combination with coal, oil, or natural gas to power electrical generation plants. Large utility and energy corporations view fast-growing GE trees as a way to meet high demand for wood pellets in the US and Europe. As discussed in Chapter 2, industry's push to commercialize GE eucalyptus, engineered to withstand colder temperatures, will expand tree plantations in southern states and escalate wood pellet production.

In the US, over 30 wood pellet production facilities are operating or in development across the South,[62] and hundreds of new "renewable energy" facilities have been developed to burn biomass as a result of government support for wood products as an alternative fuel.[63] However, emerging science reveals that burning trees and/or wood pellets produces high rates of greenhouse gas emissions and other pollutants and is not a sustainable solution to replace fossil fuels or coal.[64]

Large utility and energy corporations view fast-growing GE trees as a way to meet high demand for wood pellets in the US and Europe. Industry's push to commercialize GE eucalyptus, engineered to withstand colder temperatures, will expand tree plantations in southern states and escalate wood pellet production.

National and international energy policies significantly encourage technologies such as GE trees.

European companies are also heavily pursuing wood pellet burning in order to lower emissions and meet government energy targets. Wood pellets are shipped from ports in the southeastern US to Europe. In 2012, the US was the largest exporter of wood pellets in the world, increasing exports by 70 percent that year.[65] In efforts to comply with EU sulfur dioxide restrictions, wood pellets are typically co-fired with coal to fuel power plants.[66] However, studies show that while wood pellet biomass does lower sulfur dioxide emissions, it increases a variety of other emissions and ultimately prolongs the life of these polluting power plants, all under the guise of climate-friendly energy production.[67]

INTERNATIONAL INSTITUTIONS AND AGREEMENTS

There is often a symbiotic relationship between domestic energy policies aimed to reduce greenhouse gas emissions and international agreements and institutions. Entities such as the World Bank provide massive funding for energy initiatives; the World Trade Organization influences domestic rules pertaining to energy; and efforts such as the UN Framework Convention on Climate Change are powerful arenas where energy mandates and policies are crafted. The following are two summary examples of how international policies influence issues such as GE trees and plantations.

Clean Development Mechanism

Carbon trading and credit schemes seek to incentivize investment in projects that help reduce greenhouse gas emissions. The Clean Development Mechanism (CDM) is an emissions reduction credit program that is part of the Kyoto Protocol. The CDM promotes clean development projects, i.e., those that reduce emissions compared to a defined baseline, in developing countries.

Similar to renewable fuel mandates, the CDM and other carbon credit schemes have incentivized investment by industrial countries and corporations in projects in the global South. Some of the CDM projects are land intensive and continue to exert pressure on native ecosystems through land use change. For example, a Norwegian timber company, Green Resources Ltd., replaced nearly 7,000 hectares of natural Tanzanian grassland with monocultures of pine and eucalyptus trees that the company is growing to obtain carbon credits to sell to the government of Norway.[68]

Corporations based in industrialized countries often utilize cheap land and labor in developing countries to meet CDM emission reduction targets. Enormous tracts of land are being acquired for biofuel plantations, afforestation, and other uses under the CDM banner. The acquired land is frequently claimed to be "unproductive" or "degraded"; however, such lands often support indigenous, nomadic, and pastoral populations. These forests, grasslands, and other lands are typically biodiverse ecosystems that sequester high levels of carbon in their original form.[69]

One of the central critiques of the CDM is that it does not discourage or punish emitters, but simply allows bad environmental practices to continue and sometimes expand. Typically, corporations use the revenue gained from carbon credits to finance other destructive and land-intensive projects. For example, Sierra Gold Corporation, a Canadian mining company that operates in Sierra Leone, plans to use revenue from its 45,527-hectare CDM project, a Kiri tree plantation valued at $714 million over 50 years, to expand mining operations in West Africa.[70] The derived value of biofuel mandates and carbon credits increase intensive land use that threatens the very ecosystems these climate change mitigation techniques were put in place to protect.

The derived value of biofuel mandates and carbon credits increase intensive land use that threatens the very ecosystems these climate change mitigation techniques were put in place to protect.

Reducing Emissions from Deforestation and Forest Degradation

The UN's Reducing Emissions from Deforestation and Forest Degradation (REDD) program assigns value directly to forests in an effort to save and reestablish threatened forests. One of the controversial aspects of REDD is that the UN's definition of "forest" does not distinguish between natural forests and plantations. Thus, planting highly destructive monoculture plantations such as oil palm and eucalyptus are considered reforestation. REDD projects are in the process of being integrated into the UN's CDM trading scheme.[71]

* * *

As this chapter outlines, forests are multi-functional and GE trees and plantations cannot replace the myriad roles of forests. Understanding drivers of deforestation is critical to crafting truly sustainable solutions to restore and maintain forests. In the next chapter, we profile GE trees and discuss negative environmental and socio-economic ramifications.

GENETICALLY ENGINEERED TREES—LINK TO LAND GRABS

Industrial nations are increasingly acquiring land from developing countries to satisfy the demand for food and biofuel of consumers in the North. These "land grabs" by corporations or foreign governments for agricultural plantations often have tragic consequences for local populations. Foreign investors promise that land acquisitions will provide jobs, food security, and economic development. However, the history of these projects reveals the opposite. Instead, communities that have lived in regions for generations, often with no formal claim to the land, are frequently left without livelihoods, food, or water, and are marginalized and left with little recourse.[1]

For example, of the 405 land grab projects reviewed by the World Bank, the majority of these projects were owned by foreign entities growing food for their domestic populations. The remaining projects were primarily devoted to biofuel crops and cash crops for export, leaving local populations landless and hungry.[2] It is estimated that from 2006 to 2009 alone, between 37 million and 49 million acres of farmland were secured through land grabs.[3]

The proliferation of land grabs perpetuates the decline of biodiverse forests and threatens the food security of local populations. Proponents of these acquisitions argue that only "marginal," "idle," or "degraded" land is acquired. However, most land claimed to be idle or marginal are collective lands that have been used by local peoples for centuries. Under the guidance of accumulated knowledge of generations, these ecosystems are a vital resource for water, food, medicinal plants and herbs, and other materials. Additionally, these lands are repositories of plants and creatures that have continuously adapted to harsh conditions and can serve as a vital reserve for genetic diversity needed for adaptation to drought, disease, and pests expected to increase with climate change.[4]

Tree plantations, as a source for biofuels and biomass, are major offenders in this growing trend. Genetically engineered trees are being designed specifically for the purpose of fullfilling biofuel mandates of industrial countries and international programs. This provides strong economic incentives for land grabs. (See end of Chapter One.)

An oil palm plantation land grab by a US company in Cameroon provides an illustrative example of the many tensions that arise when plantations are forcibly introduced to a region. The plantations proposed by Herakles Farms, an affiliate of Herakles Capital, threaten to negatively impact up to 45,000 people according to on-the-ground estimates from non-governmental organizations working in the area.[5] The company argues that the plantation will ultimately bring new jobs to the area, but there is little evidence that local populations will benefit.[6] Land grabs such as this one typically result in mass displacement of people from their homes and lands. Despite strong opposition from local communities, the project continues to move forward.

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[6] Ibid.

CASE STUDY OF OIL PALM PLANTATIONS IN INDONESIA

The modern day history of oil palm plantations demonstrates how tree plantations have contributed to deforestation. Palm oil, derived from oil palm trees, is a burgeoning commodity in Southeast Asia, Central America, and West and Central Africa and is used largely for edible oil, biofuels, processed foods, and personal care products.

Originally perceived to be an economic boon for tropical countries and an environmentally friendly source for biofuel, palm oil production has increased rates of deforestation and other environmental harms and resulted in loss of livelihoods, land, and overall marginalization of local communities.

Between 2000-2009, Indonesia supplied more than half of the global palm oil market, making it the world leader.[1] Indonesia's palm oil exports increased by nearly 11 million tons over the course of the decade, roughly 27 percent per year.[2] Yet despite the income generated for the national economy, the increased production has not translated into national wealth of ecosystems or communities.

As demand for palm oil increases, plantation development inevitably expands and encroaches on forestland. Oil palm plantation expansion has led to the astonishing loss of over half of Indonesia's forests, mostly tropical lowland forests, since the 1960s.[3] Currently, there are six million hectares of oil palm plantations in Indonesia; the country has plans for another four million hectares by 2015 dedicated solely to biofuel production.[4] Indonesia projects that it will export about 28 million tons this year, with 17 to 18 million tons destined for India, China, and Europe.[5] This massive loss of Indonesian forests is threatening the remaining natural habitat of several endangered species, such as the orangutan and Sumatran tiger.[6]

Moreover, this rapid expansion has meant that local populations have been forced off their land in order to make way for plantations. It is estimated that 60-90 million Indonesians rely on native forests for their livelihoods, with 45 million living directly in forested areas.[7] Thus far, the Indonesian Human Rights Commission has documented over 5,000 land and human rights conflicts, almost entirely related to oil palm development.[8] (See *Genetically Engineered Trees—Link to Land Grabs.*)

Palm oil-based biodiesel was once touted as a solution to climate change, but today, Indonesia emits more greenhouse gases than any country besides China and the United States, largely due to its oil palm operations.[9] Recent research has revealed that oil palm development, which often involves the clearing of intact forestland, can contribute far more greenhouse gases to the atmosphere than it helps to avoid. For instance, each hectare of peatland drained for oil palm plantations releases an estimated 3,750-5,400 tons of carbon dioxide over the course of 25 years.[10]

Though technically illegal, fires are regularly and deliberately set by palm oil companies between June and September, Indonesia's dry season, to clear fields and forestland for oil palm plantations.[11] The smoke affects not only local inhabitants, but also creates life-threatening smog in neighboring countries. This year (2013), smog reached record levels—Malaysia declared a state of emergency where the haze triggered one of the country's worst pollution levels, while Singapore urged people to remain indoors due to "hazardous" levels of pollution.

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CHAPTER TWO

OVERVIEW OF GENETICALLY ENGINEERED TREES

Genetic engineering of trees is aimed at accelerating the proliferation of large-scale, industrial monoculture tree plantations and increasing profits for biotechnology companies as well as paper, biofuel, lumber, and energy industries.

Planting tree plantations is permanent *deforestation.... The extensive planting of just one exotic species removes thousands of native species.*
—Bernd Heinrich, *The Trees in My Forest*[1]

Genetically engineered (GE) trees are a new frontier of plant biotechnology. In the same way that Monsanto and other agribusiness giants transformed the landscape of agriculture with GE crops, ArborGen and other tree biotechnology companies have a vision of a forest products industry dominated by plantations stocked with their proprietary GE trees.

Trees are being genetically engineered for a range of purposes: easier processing into biofuels or paper; faster growth for biomass power generation; altered wood structures for lumber; and incorporated resistance to herbicides and pests that make it easier to cultivate tree plantations. Genetic engineering of trees is aimed at accelerating the proliferation of large-scale, industrial monoculture tree plantations and increasing profits for biotechnology companies as well as paper, biofuel, lumber, and energy industries. ArborGen, the leading biotechnology tree company, has projected its profits will boost yearly sales from $25 million to $500 million in 2017 if GE trees are commercialized.[2]

In the US and most countries, prior to any field trials or commercialization of genetically engineered plants or traits, biotechnology developers must petition the appropriate federal agency for approval. Genetically engineered pines, poplars, eucalyptus, and American chestnuts would be used mainly as raw material for biomass-fueled electricity operations and chemical production (e.g., terpene) and also for traditional lumber and paper products. A smaller segment of the nascent GE tree industry is creating fruit and nut trees with altered qualities, including novel disease and pest resistance and changes in ripening or storage characteristics. Some trees are being engineered to ostensibly store carbon as a climate change mitigation tactic or to be "climate ready" and grow in extreme conditions.

Even after some domestication, many plantation trees retain the ability to thrive in the wild or can still cross with wild relatives, increasing the likelihood that GE trees could establish in native forests or other unmanaged ecosystems.

"Heritage trees" such as the American chestnut are being marketed as a way to restore forest trees that have recently been decimated by disease. Such projects that claim to save forests, reduce greenhouse gas emissions, and promote other ecological practices are often advertised by industry in order to capture the hearts and minds of the public and smooth the way for more financially lucrative and controversial endeavors. However, as this chapter demonstrates, tree plantations and GE trees simply perpetuate an industrial, chemical-intensive model instead of taking more holistic, systemic approaches.

This chapter profiles GE trees and examines potential impacts. How far along are different projects, and what do critics say about them? Do GE trees have a place in our vision of a sustainable future? These issues and more are discussed in this section.

SPECIAL ATTRIBUTES OF TREES

Trees are often different from field crops in ways that make genetic engineering particularly risky. For example, many trees reproduce over very long distances, have long life spans (ranging from decades to centuries), and represent keystone species in complex forest ecosystems. This section reviews some of these important characteristics and illustrates why trees present a particular challenge to genetic engineering and why it is essential to pursue a precautionary path and conduct long-term, comprehensive research before determining if GE trees should be cultivated. Much of the information in this section draws from Steinbrecher and Lorch's 2008 report, "Genetically Engineered Trees & Risk Assessment: An overview of risk assessment and risk management issues."[3]

LONG LIFE SPAN OF TREES

Trees live for decades or even centuries. In contrast, most field crops are annuals that complete a whole life cycle in a single year, biennials that take two years from seed to seed (e.g., carrots, sugar beets), or rarely, perennials that are managed on several-year rotations (e.g., alfalfa). Consequently, the process of engineering and testing GE trees progresses more slowly than for crops.

Over its life span, a tree requires resilience and adaptability as it encounters varied and unpredictable conditions from changing weather and climate to different kinds and numbers of pests and pathogens. Short-term field tests of GE trees do not provide comprehensive data or proper risk assessments of long-term tree resilience and adaptability. For example, disease resistance engineered into a heritage American elm will need to protect the tree for the 150 years or more life span of the tree, making it difficult to assess the durability of the engineered disease resistance and the potential unintended consequences.

THE WILD NATURE OF TREES

Many agricultural crops have been domesticated for thousands of years. As a result, most crops have diverged from their wild relatives and often are ill-adept at surviving without human care.

In contrast, the domestication of forest trees is relatively new, having begun less than a century ago.[4] Even after some domestication, many plantation trees retain the ability to thrive in the wild or can still cross with wild relatives, increasing the likelihood that GE trees could establish in native forests or other unmanaged ecosystems.

Fruit trees are often varieties that have been propagated for centuries, typically by grafting or other vegetative methods to maintain specific characteristics. Even so, many fruit trees easily cross with wild species, and some can also become feral.[5]

LONG-DISTANCE REPRODUCTION

Many trees produce large quantities of pollen and seeds that are dispersed over great distances via wind, water, and wildlife. For example, the eastern cottonwood can produce almost 30 million wind-dispersed seeds in one season,[6] and some pine pollen can travel more than 25 miles and still be viable.[7] Fruits are especially attractive to animals, and their seeds can be transported in digestive tracts to be deposited far from parent trees. This means that if there are suitable habitats for seedling establishment or compatible partners for pollination, GE trees can "escape" from plantations into the wild, miles away, and eventually spread transgenes into wild tree populations.

Additionally, some trees are able to reproduce asexually through vegetative propagation.[8] In some species, isolated twigs can root or roots can form buds and grow into mature trees. Thus, even if they are engineered to have no pollen or seeds, vegetative reproduction could result in establishment of GE trees outside of cultivated plantations.

ECOSYSTEM COMPLEXITY

All ecosystems involve interactions between many species and environments; however, forest ecosystems are especially complex.[9] Forests are multifunctional and multi-layered structures that change seasonally and over the years, providing food,

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shelter, microclimates, and other habitat requirements for a wide array of organisms.

The complexity of trees and forest ecosystems necessitates that comprehensive, long-term risk assessments, while difficult, should be required before any GE tree is allowed to be commercialized. For example, interactions with other organisms must be evaluated, both in the proposed planting location and other locations where the tree could conceivably spread, and during different stages in the tree's lifetime. Indirect effects on other organisms through disruption of the food web must also be considered. In addition, hydrological, climatic, genetic, cultural, and socioeconomic impacts need to be considered over time, in specific locations, and under anticipated stresses. These impacts must all be evaluated in relation to one another.

The complexity of trees and forest ecosystems necessitates that comprehensive, long-term risk assessments, while difficult, should be required before any GE tree is allowed to be commercialized. Interactions with other organisms must be evaluated, both in the proposed planting location and other locations where the tree could conceivably spread, and during different stages in the tree's lifetime.

PROFILES OF GE TREES

Currently, there are five GE trees approved for commercial planting: virus-resistant papaya and plum in the US, another variety of virus-resistant papaya in China, and two species of poplar engineered for insect resistance in China. Only two are approved in the US: the GE papaya, which is grown on approximately one thousand acres in Hawaii,[10] and the GE plum, which has yet to be planted on a commercial scale.

In China, a European black poplar engineered with an insecticidal gene from the soil bacterium *Bacillus thuringiensis* (Bt) is being widely grown with more than one million trees planted on hundreds of hectares by 2003.[11] Another insect-resistant poplar was also approved for commercialization in China, a hybrid between white poplar and two Chinese poplar species. It is engineered with Bt and a novel insecticide derived from the arrowhead lily, arrowhead proteinase inhibitor (API).[12] There are no reliable reports of how many of these GE white poplar hybrid trees have been planted. Finally, China also has commercialized a virus-resistant papaya, similar to the Hawaiian varieties, called Huanong No. 1. Again, there are no reliable estimates of acreage planted to Huanong No. 1 papaya, but it is likely to be widely planted in China.[13] Both Hawaiian and Chinese virus-resistant papaya trees are also being grown in Hong Kong.[14]

There have been hundreds of field trials with dozens of GE tree species around the world.[15] Worldwide and in the US, trees in the genus *Populus*—such as poplars, aspens, and cottonwoods—along with pines, other conifers, and eucalyptus, have been the most common experimental GE trees. Various fruit trees such as apples and citrus are also being field tested.[16]

Field tests often involve several transgenic lines with different combinations of novel genes at a number of sites and may span several years. Currently, there are over

1,000 acres of GE tree field trials in 20 states. ArborGen, the largest tree biotechnology company in the US, has planted over a quarter million GE eucalyptus trees alone. In 2010, the US Department of Agriculture (USDA) approved a widespread planting of experimental GE eucalyptus, covering 28 open-air test sites across seven southern states totaling 330 acres. (The Center for Food Safety filed a lawsuit challenging these field trials—see *The First Genetically Engineered Tree Legal Challenge*.)

Building on these field trials, ArborGen has submitted a petition to the USDA to allow commercial plantings of two lines of its freeze-tolerant eucalyptus. This trait is intended to expand the geographic area where eucalyptus can grow. These will likely be the first commercialized GE forest trees in the US and will be harvested primarily for biofuels, wood pellets, lumber, and paper products unless approval is denied.

Genetically engineered apples that brown more slowly after being sliced or bruised are also pending commercial approval. Companies involved in tree biotechnology are preparing to attempt to commercialize several other kinds of trees with different traits in the near future.

As already noted, in most countries, all GE crop developers must submit a petition to the appropriate branch of the federal government, which may then grant or deny approval for field trials and/or commercialization. This section examines specific GE trees already commercialized, growing in field trials, as well as trees that are pending federal approval for commercialization in order to illustrate potential impacts on environment and economies.

Worldwide and in the US, trees in the genus *Populus* are being genetically engineered with a variety of traits, including increased growth rates; lower levels of lignin to improve processing for paper, wood pellets, and biofuels; pest and herbicide resistance for more efficient plantation management; and other traits that are claimed as "confidential business information."

POPLAR TREES

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These GE poplars are often closely related to wild species growing in native forests or in non-GE plantations, raising the specter of escape of seeds or pollen into the wild where poplar trees with GE traits could then become established.

Around 30 different poplar species grow from subtropical Florida to sub-alpine zones in North America and Europe.[18] Many species are also native to Asia. This large habitat range of compatible wild species, in addition to their prodigious production of wind-dispersed pollen and seed, heightens the risk of GE poplars moving into native forest ecosystems. Steve Strauss, a respected GE poplar researcher and a proponent of GE trees, acknowledges the risks involved, saying that "the scale of potential impact of transgenic poplars is large because of their extensive dispersal of pollen and seed."[19]

Escape of transgenes from GE crops to wild plants and ecosystems has occurred before. For example, Monsanto's experimental Roundup Ready bentgrass field tested in 2002 continues to spread and cross with wild grasses miles from original test sites in eastern Oregon.[20] In the mid-2000s, the transgene in Roundup Ready alfalfa moved from regulated test plots into feral alfalfa populations in several western states.[21]

Additionally, GE crops have repeatedly contaminated conventional field crops. Star-Link corn, which was not approved for human consumption due to its potential to cause allergies, was found in taco shells in 2001.[22] Bayer's unapproved Liberty Link rice was found growing in five southern US states and was detected in rice exports.[23] Most recently, Monsanto's GE wheat was found growing in Oregon even though field trials of the wheat had been suspended for several years, and the wheat was never approved for commercial use.[24] Such incidents can result in severe economic harm to farmers and producers. These examples highlight the need to seriously address the potential escape of transgenes from poplars and other GE trees into wild areas and non-GE plantations and orchards.

A 2011 study found that reduced lignin in GE poplars results in decreased wood strength and stiffness. Eventually, these reduced-lignin trees may be less able to cope with environmental stresses, including extreme weather events, insect pests, and pathogens, resulting in less resilient forests.

GE Poplars and Biofuels

For the last decade, US biofuels have largely been derived from corn. In recent years, the biotech tree industry has pursued producing biofuels from cellulosic ethanol derived from trees or other plant material. Altered or reduced lignin, a critical structural component of wood, makes it easier for companies to break down woody biomass and access sugars for ethanol production. Poplars in particular are being engineered to produce lower levels of lignin for biofuels. However, GE poplar trees with lower lignin, a complex chemical that slows the biotic breakdown of organic matter, could impact forest health in numerous ways.

Lignin is essential to the resiliency of tree species in the wild. A 2011 study found that reduced lignin in GE poplars results in decreased wood strength and stiffness. The study projected that in forest environments, GE trees may outcompete native trees for access to sunlight. The accelerated growth rate can then cause the GE trees to collapse.[25] Another study found that reduced-lignin poplar had ultra-structural differences in wood and a 10 percent decrease in wood density.[26] An examination of a number of plants found that in general, reduced lignin negatively impacted fitness.[27] Consequently, GE-altered or reduced-lignin trees may be structurally weaker than non-GE wild relatives and may be more susceptible to pests and pathogens.

Even if GE poplars exhibit decreased fitness levels over the long term, in the short term, fast-growing, reduced-lignin GE poplars can potentially outcompete non-GE poplars during seedling and sapling stages. Eventually, these reduced-lignin trees may be less able to cope with environmental stresses, including extreme weather events, insect pests, and pathogens, resulting in less resilient forests.

Along with maintaining structurally sound trees and helping to repel pests, lignin plays an important role in decomposition. Soil structure is highly dependent on balanced decomposition of leaf litter and other forest detritus. Outside of arid or semi-arid climates where there is bountiful sunlight and fewer bacteria and enzymes to break down plant material, GE trees with reduced lignin are likely to decompose more rapidly than their non-GE counterparts, thus disrupting forest soils.[28]

Reducing lignin content can also affect a tree's capacity to store carbon. For example, GE aspen trees with altered lignin store 30 percent less carbon.[29] This, along with increased decomposition rates, could result in higher levels of atmospheric carbon, contributing to rather than ameliorating climate change. By the time these negative consequences become apparent, damage to forests may be severe and irreversible. Both critics and proponents of tree biotechnology agree that measures must be taken to keep GE poplars and other GE trees out of native forests and natural areas.[30]

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GE Poplars in China

In China, GE poplars have been commercialized already, apparently without effective suppression of their ability to reproduce. In 2002, GE black poplar (*Populus nigra*) trees with Bt insect resistance were approved by the Chinese government for commercial planting.[31] Over one million GE black poplar trees had been planted in commercial plots by 2003.[32] At about the same time, the Chinese government approved commercialization of a white poplar hybrid carrying two insect-resistance genes, a Bt Cry1Ac gene and an API gene.[33] There are no estimates of how many GE white poplar hybrids have been grown. Tracking the planting and containment of these GE poplars has been a difficult task for the Chinese government, and there are no reliable data on transgenic contamination in China's seven million hectares of non-GE poplar plantations or native forests. Wang Huoran of the Chinese Academy of Sciences told an FAO panel that GE poplar trees "are so widely planted in northern China that pollen and seed dispersal cannot be prevented.[34]

As with the reduced lignin trait, insect-resistant poplars exhibiting Bt and API traits could have ecological impacts if non-target insects are harmed, especially if those insects are threatened or endangered. The API toxin, for example, has not been used in GE agriculture before, and little is known about what native insects it might harm. However, what is known is that proteinase inhibitors such as API are generally less selective than Bt toxins, suggesting that a wider variety of non-target insects could be impacted.

Research on ways to prevent the movement of transgenes from GE poplars—mainly by inhibiting development of flowers, pollen, or seeds—is in development.[35] Some of these methods are being field tested; however, it is extremely difficult to totally suppress reproduction, and even a small amount of gene flow can eventually spread GE traits to trees in the wild.

PINE TREES

After poplars, *Pinus* is the most common genus being genetically engineered in the US, with major efforts to engineer the loblolly pine. The loblolly pine (*Pinus taeda*) is native to most of the southeastern US, with a natural range stretching from New Jersey along the coastal plain south to eastern Texas.[36] It is currently the most widely planted commercial timber species in southern US states.[37] Loblolly pines naturally produce terpenes, molecules that are the main component of the liquid fuel turpentine. Pine terpene is an established fuel source, with over 1 billion metric tons collected each year either by tapping live pine trees or as a co-product in pulp and paper production.[38] Researchers at the University of Florida and ArborGen received a collaborative three-year, $6 million grant from the US Department of Energy to use both conventional plant breeding and genetic engineering to increase terpene storage capacity in loblolly pines from 4 percent of dry weight to 20 percent. Increased terpene production will be used for transportation fuel.[39] Loblolly pines are already quite flammable, and increasing their terpene content is likely to increase the risk of dangerous wildfires that could spread from GE plantations to natural forests and populated areas. Also, in the long term, if high-terpene trees become common in natural forests from GE seed dispersal or cross-pollination, the forests themselves could become more flammable. Since viable pollen from loblolly pines can disperse over 40 km,[40] tracing and preventing transgenic contamination in forests will be very difficult.

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Loblolly pines are also being engineered for other traits such as reduced or altered lignin content and faster growth.

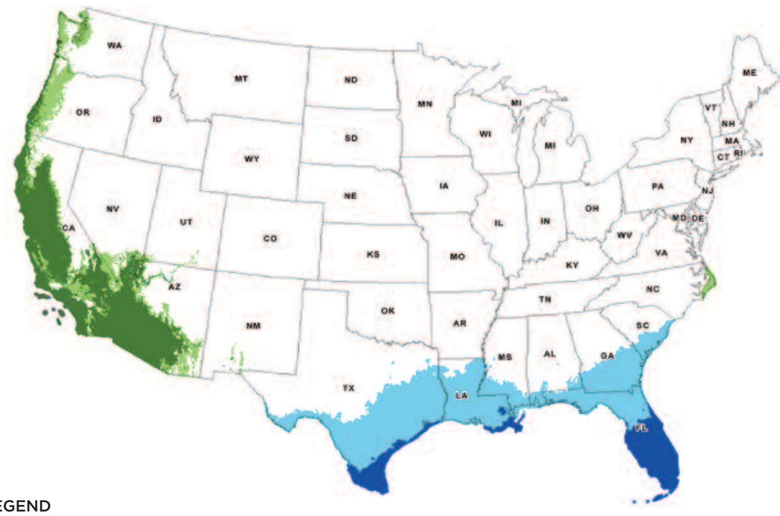
EUCALYPTUS TREES

Species of the *Eucalyptus* genus are the world's most widely planted hardwood trees due to their fast growth rate and wide adaptability to different environments. Eucalyptus species are currently used in the production of pulp for paper and various wood products. In Brazil, they serve as a charcoal supply to support the steel industry. As more countries promote the production of biofuels, eucalyptus plantations will likely be in greater demand for cellulosic biofuel production. One Brazilian forest-asset company claims that the eucalyptus market has room to expand by 500 percent over the next 20 years.[41]

In the US, most species of eucalyptus are only able to grow in subtropical areas or in regions of the country that do not have hard freezes, including Hawaii, parts of California and the Pacific Northwest, and extreme southeastern states. However, in 2011, ArborGen submitted a petition to the USDA to commercially cultivate two lines of freeze-tolerant eucalyptus (FTE). The trees were developed by inserting the C-Repeat Binding Factor gene for freeze-tolerance from the small flowering plant *Arabidopsis thaliana* into a commercial hybrid of *Eucalyptus grandis* and *E. urophylla*.[42]

Along with freeze-tolerance, the GE eucalyptus lines are engineered to eliminate pollen production in order to minimize the likelihood of transgenic contamination.

USDA PLANT HARDINESS ZONE MAP



LEGEND

- Hardiness zones 8b and 9a where the GE eucalyptus could be grown and ArborGen plans to commercialize.
- Hardiness zones 9b and higher where both the non-GE and GE eucalyptus could be grown commercially.
- Other areas of hardiness zone 8b and 9a.
- Other areas of hardiness zones 9b and higher.

DARK BLUE AND DARK GREEN show off where non-GE eucalyptus can grow now based only on average annual low temperatures. All colored areas (Plant Hardiness Zones 8b and higher) show where freeze-tolerant GE eucalyptus could be grown based only on average low temperatures greater than 15 degrees Fahrenheit. Blue is where the petitioner intends to market it if approved. The USDA Plant Hardiness Zone Map is the standard by which gardeners and growers determine which plants are most likely to thrive in a location.

Source: United States Department of Agriculture Animal Plant Health Inspection Service, Genetically Engineered (GE) Eucalyptus. (Virtual meeting presentation.)

However, as discussed in more detail later in this report, this alteration will not fully eliminate the risk of GE eucalyptus spreading into natural areas.

ArborGen's FTE lines are engineered to tolerate temperatures as low as 15 degrees F, allowing commercial plantings in USDA hardiness zone 8b or higher (see Figure 1). Eucalyptus have been grown commercially in Florida for about four decades, but fast-growing timber and pulp species are limited to the southern part of the state where the climate is more suitable. With the development of freeze-tolerant eucalyptus, the cultivation range is likely to further expand in the southeastern US and to new areas of the Pacific Northwest. These GE eucalyptus have the potential to grow much faster than most pine plantations and are expected to replace pines through much of the southeast.

It is no accident that the GE eucalyptus was engineered to grow in the southeastern part of the US as more trees are needed to stock the wood pellet manufacturing facilities proliferating across this region. Wood pellets are used for biomass, in conjunction with oil, gas, and coal, to fuel electricity plants and other energy industries in both Europe and the US. In 2012, wood pellet exports from southern ports increased by

As more countries promote the production of biofuels, eucalyptus plantations will likely be in greater demand for cellulosic biofuel production.

70 percent, making the US the world's largest exporter of wood pellets.[43] Wood biomass is often marketed as being a sustainable alternative to burning fossil fuels; however, science now concludes that burning trees is extremely polluting and can emit more greenhouse gas emissions over time than coal, oil, and natural gas.[44]

In February 2013, the Animal and Plant Health Inspection Service (APHIS) of the USDA announced its intent to prepare an Environmental Impact Statement (EIS) prior to deciding whether to grant commercial approval of the GE eucalyptus tree. An EIS is the most rigorous vehicle available under the National Environmental Policy Act for assessing various impacts and considering alternative actions. Prior to this announcement, APHIS had only prepared three EISs in its history of regulating GE plants, all in response to legal actions. (See *The First Genetically Engineered Tree Legal Challenge*.) APHIS' decision to prepare an EIS for GE eucalyptus reveals the agency's recognition of the potential for considerable and unique adverse impacts of GE trees.

PAPAYA TREES

GE Papaya in the US

The first GE fruit to be commercialized was virus-resistant papaya in Hawaii. In the 1990s, papaya ringspot virus (PRSV), which had devastated papayas in other parts of the world, spread to Hawaii's main papaya production area. In anticipation of this, researchers at Cornell University and the University of Hawaii developed a GE payaya with resistance to the virus by incorporating the viral coat protein gene of PRSV into papaya.[45] APHIS deregulated the PRSV-resistant GE papaya in 1996, and GE varieties SunUp and Rainbow became available to Hawaiian growers in 1998. These two GE varieties demonstrated high levels of resistance to PRSV and are widely planted in Hawaii today.

In addition to the GE papaya grown in Hawaii, GE PRSV-resistant papaya developed by the University of Florida was deregulated in 2009 with the apparent intent to grow the fruit in Florida, Puerto Rico, and possibly other parts of the Caribbean.[46] However, at the time of report publication, there is no indication that this GE papaya is being produced.

Soon after its commercialization, there were two major negative impacts of GE papaya: 1) loss of export markets for Hawaiian papaya, and 2) widespread transgenic contamination of organic and non-GE trees.

For decades, Japan was the largest importer of Hawaiian papaya, highly valued for its superior quality and taste. In 1996, nearly $15 million worth of Hawaiian papaya was shipped to Japan.[47] However, due to Japanese consumer concerns about GE papaya, US exports suddenly plunged; the price of papaya per pound declined by 35 percent,[48] and production fell by almost 34 percent.[49] By 2006, the total value of the Hawaiian papaya industry was half of what it was in 1995.[50] And, even though Japan now allows imports of GE papaya, exports to Japan were only $1 million in 2011.[51]

Today, roughly 85 percent of Hawaiian papaya is transgenic. This has resulted in widespread transgenic contamination of organic and non-GE papaya.

Today, roughly 85 percent of Hawaiian papaya is transgenic.[52] This has resulted in widespread transgenic contamination of organic and non-GE papaya. Only six years after GE papaya was adopted, research by Hawaii SEED, a local NGO, revealed that 50 percent of seed samples collected from organic or feral papaya on the island of Hawaii tested positive for GE material.[53] And while Hawaiian GE papaya trees are largely resistant to PRSV, many are now more susceptible to the fungal infections black spot fungus and phytophthora.[54]

Genetically engineered trees can become established, perhaps unintentionally, far from commercial fields and then become difficult to monitor, regulate, or track should concerning issues arise.

GE Papaya in China

A PRSV-resistant GE papaya called Huanong No. 1 was approved for commercialization in China in 2006[55] and is rumored to be widely planted. It is similar to Hawaiian GE papaya varieties and is sold to farmers through a Chinese seed company as already germinated seedlings.

Hong Kong is an importer of GE papaya fruit from both mainland China and Hawaii, and apparently some consumers in Hong Kong have planted seeds from these papayas in their backyards for home use.[56] Although the planting of GE crops is regulated in Hong Kong, requiring risk assessments and permits, recently GE papaya trees have been exempted from regulation because enforcement "would be a challenge."[57] Hong Kong government officials took note of a "survey conducted in 2010–2011 indicating over 44 percent of locally grown papaya are GE products" and that these are mainly grown by older people in the suburbs that either would not know about the need to register their trees or would not be able to afford the application fee.

This, along with the transgenic contamination in Hawaii, illustrates the difficulty of maintaining control over propagation of GE fruit trees once the fruits are marketed. Genetically engineered trees can become established, perhaps unintentionally, far from commercial fields and then become difficult to monitor, regulate, or track should concerning issues arise.

APPLE TREES

In 2012, Okanagan Specialty Fruits submitted a petition to APHIS to deregulate two types of GE apples. The apples are engineered to reduce the rate at which they brown after they have been sliced or bruised.[58] If approved, the apples will be sold under the "Arctic Apple" name in two varieties, Granny Smith and Golden Delicious. Browning in apples occurs due to the polyphenol oxidase (PPO) enzyme, which Okanagan has reduced to 10 percent of normal levels by inserting an engineered gene that silences a family of PPO genes expressed throughout apple trees, including in the fruit. The company will market the non-browning apples to companies selling pre-packaged sliced apples and to the fast food industry.

Research suggests that plants may be more vulnerable to pests and pathogens when PPO genes are silenced. In limited monitoring by the company, their GE Granny Smith apple showed increased damage from the tentiform leafminer, an insect found in the northwestern US, a large apple-growing region.[59] More rigorous testing specifically designed to determine effects of lower PPO on pests and pathogens is needed.

Apple growers are concerned that GE apple trees could cross-pollinate with organic and conventional trees. While cross-pollination would not contaminate an entire tree, it could result in transgenic apple seeds. The presence of transgenic seeds in fruit destined for GE-sensitive markets could result in economic harm to the industry. Okanagan acknowledges the possibility of transgenic contamination in its deregulation petition: "An adverse agro-ecological consequence is the potential for contamination of seeds in conventional or organic apple crops with the PPO transgene as a result of pollination flow from transgenic trees."[60] A number of factors determine the likelihood of contamination, including overlapping flowering times, the distance between orchards, and the presence of a buffer row of trees.[61]

The US Apple Association opposes these GE apples, recognizing that the image of apples as wholesome and healthy fruit could be compromised.[62] The development of the GE non-browning apple has also been met with skepticism from consumers. A 2012 Canadian survey found that nearly 70 percent of participants were against the approval of the GE apple.[63] Given the harsh economic and environmental consequences experienced by papaya producers when the industry converted to GE papaya, impacts to apple growers could be even more severe because the US apple industry is over 300 times larger than the papaya industry.[64]

No health studies based on feeding trials with GE Arctic Apples have been reported; some consumers have concerns about eating these untested apples. Although Okanagan plans to identify fresh apples with the Arctic Apple logo, some of the GE apples may be mixed with non-GE apples in sauces and juices. Because there are no current GE labeling requirements in the US, consumers will not know if they purchase GE apples, especially in prepared foods. Okanagan and the USDA are also developing GE peaches, pears, and cherries,[65] and the USDA is field testing GE apple trees with either more or less cold tolerance.[66]

PLUM TREES

A plum engineered for resistance to plum pox virus (PPV) was deregulated in 2007; however, the GE plum, called HoneySweet, will not likely be grown commercially anytime soon.[67] The GE plum was created in case PPV becomes more widespread

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and more difficult to manage, but at present, the virus is under control and contained to parts of Pennsylvania.[68]

CITRUS TREES

Citrus trees, originally from Asia, are now grown around the world wherever it is warm enough for them to thrive. These include oranges,[69] grapefruit, lemons, limes, and other fruits that comprise the many species and hybrids in the genus *Citrus*.[70] Although there are no GE citrus trees in commercial production, field trials have been going on in the US since the late 1990s.[71]

Of more than two dozen GE citrus field tests in the US, all have been directed at reducing diseases.[72] There have been tests of resistance to the Citrus tristeza virus (CTV), the bacterial diseases citrus canker and citrus greening (or Huanglongbing, HLB), and the fungal diseases scab and leaf spot. Also, a few projects are aimed at killing the insects that transmit citrus diseases, known as vectors. About 30 different engineered genes have been used in these tests, including some that target specific pathogens and others that are designed to provide broad resistance to several pathogens at once. Genetically engineered citrus field tests have been registered by Texas A&M and Texas Agricultural Experiment Station, University of Florida, USDA-ARS, US Sugar Corporation, Integrated Plant Genetics Inc., and University of Hawaii.

The earliest field trials of GE citrus in the US were for grapefruit engineered to resist CTV, a serious disease that had decimated citrus groves around the world.[73] After more than ten years of further field tests by several research groups, there are still no commercially viable GE CTV-resistant citrus trees. Researchers had hoped that GE methods involving inhibition of viral coat protein gene expression—successful in a few crops such as papayas, plums, and summer squash[74]—would work with CTV. However, they discovered that "incorporation of pathogen-derived resistance by plant transformation has yielded variable results, indicating that the CTV-citrus interaction may be more specific and complex than initially thought."[75]

Bacterial and fungal interactions with plants are more complex still, and thus even less likely than viral infections to yield easily to GE approaches. For example, engineering plants with toxins that provide resistance to one pathogen sometimes results in promotion of a different disease as a result of poorly understood interactions between plant defenses and the specific pathogens.[76]

Whether any of these GE approaches to citrus diseases will lead to disease-resistant, commercially successful trees remains to be seen. In the long run, even if some of the GE experiments do eventually result in commercial plantings, solutions to the current diseases of citrus that involve adding one or a few genes to a tree's genome are unlikely to provide more than fleeting relief to an industry plagued by one new epidemic after another.[77] Pathogens are likely to develop resistance fairly quickly. Even worse, new highly virulent pathogens may evolve in response to resistance mechanisms used in GE trees.[78]

Citrus trees today are prone to devastation from severe disease outbreaks in part because of how they are grown. Monocultures of closely spaced, genetically uniform trees managed for high short-term productivity by applications of synthetic fertilizers and pesticides create ideal conditions for epidemics.

Citrus trees today are prone to devastation from severe disease outbreaks in part because of how they are grown. Monocultures of closely spaced,[79] genetically uniform trees managed for high short-term productivity by applications of synthetic fertilizers and pesticides[80] create ideal conditions for epidemics.[81] In contrast, organic citrus farmers grow their trees in ways that reduce the impact of diseases—creating orchards with more space between trees to decrease pathogen transmission and growth;[82] improved soil quality to boost tree nutrition and overall health;[83] and increased biodiversity from cover crops and inter-plantings, along with reduced pesticide use, to promote biological disease control.[84]

For example, in Brazil, some organic orange growers have successfully battled the bacterial disease citrus variegated chlorosis (CVS) by intercropping signalgrass, a popular forage grass, among their trees, which both improves soil fertility and eliminates the need for detrimental herbicides.[85]

Also, growing citrus without insecticides and fungicides benefits natural enemies of insects that spread disease. Parasitic wasps that attack only the Asian psyllid, the insect vector of citrus greening disease, have been released in Florida, Texas, and California, with promising results.[86] USDA scientists are also exploring the use of a natural fungus that infects and kills psyllids.[87] Because some pesticides commonly used in citrus groves are toxic to these beneficial organisms, organic methods are more likely to promote sustainable control.

Organic citrus farmers grow their trees in ways that reduce the impact of diseases—creating orchards with more space between trees to decrease pathogen transmission and growth; improved soil quality to boost tree nutrition and overall health; and increased biodiversity from cover crops and inter-plantings, along with reduced pesticide use, to promote biological disease control.

AMERICAN CHESTNUT TREES

Stretching from Maine to Mississippi and throughout eastern US forests, the American chestnut (*Castanea dentata*) was a keystone forest tree species for centuries.[88] The tree provided economically valuable lumber and chestnuts as well as important habitat for a variety of wild animals. However, chestnut blight, caused by the introduced fungal species *Cryphonectria parasitica*, has almost entirely eliminated the American chestnut from the forest canopy. First discovered in 1904 in New York, chestnut blight caused approximately 4 billion chestnut trees to perish by 1960.[89] Today, mature chestnut trees are almost nonexistent in eastern forests.

The American chestnut is known for its rapid growth and superior resistance to rot and more recently has been proposed as a candidate for woody biofuel stock.[90] These characteristics have motivated biotechnology companies such as ArborGen, Monsanto, and others to invest in developing a blight-resistant American chestnut. Duke Energy's website advertises that one day the tree can provide "high-quality lumber [and] biomass fuel for electric generation.[91] Duke Energy is particularly interested in the American chestnut's "voracious appetite for carbon," and the company plans to gain carbon credits for planting these trees on its environmentally degraded surface-mine sites in Central Appalachia.[92] (See *Genetically Engineered Trees—Providing Cover for Polluting Industries* for more details.) The company is currently sponsoring a project that hopes to begin field trials within the next few years.[93]

While both conventional breeding and genetic engineering methods are being engaged to restore the American chestnut, recent efforts seem to be heavily leaning toward transgenic American chestnut trees. In 1989, the American Chestnut Foundation (TACF) began a non-GE breeding program with the Chinese chestnut (*Castanea mollissima*), a species with high levels of blight resistance. The method uses a series of backcrosses of American with Chinese chestnuts and then intercrosses progeny to select trees with increased blight resistance that also retain substantial American chestnut characteristics. Genetically, these trees are on average 94 percent American versus Chinese chestnut.[94] This program has been successful in producing trees with superior blight resistance that are now being tested in natural settings. TACF is even lending them out to regional programs to produce locally adapted and more genetically diverse trees.

At about the same time, in 1990, Dr. William Powell at the State University of New York (SUNY) in Syracuse and Dr. Scott Merkle at the University of Georgia began to genetically engineer American chestnuts for blight resistance.[95] Research focused on inhibiting the buildup of oxalic acid, which the fungus generates when it grows. To accomplish this, a wheat gene encoding the enzyme oxalate oxidase, which breaks down the acid, was inserted into test trees.[96] In 2006, these researchers teamed up with TACF to develop GE American chestnuts with Chinese chestnut genes. TACF continues with its conventional breeding program while becoming increasingly involved in GE chestnut research.[97]

In cooperation with the above initiatives, SUNY College of Environmental Science and Forestry started the American Chestnut Research and Restoration Project. Funders of the project include ArborGen, Monsanto Fund, National Hardwood Lumber Association, Northern Nut Growers Association, USDA grants, and the Forest Health Initiative.

The Forest Health Initiative (FHI), founded in 2009, is yet another actor advancing restoration of American chestnut trees. FHI is a "collaborative effort to advance the country's understanding and role of biotechnology to address some of today's most pressing forest health challenges."[98] Stakeholders include companies such as Duke Energy and ArborGen as well as universities and non-governmental organizations. The Forest Health Initiative supervises field trials of GE American chestnuts with genes inserted from wheat, Chinese chestnut, and other trees. Genetically engineered chestnut tree field trials are in Georgia, New York, and Virginia.[99] The group is also developing GE projects for resistance in American elm trees (Dutch elm disease), ash trees (emerald ash borer), and the Eastern hemlock (hemlock woolly adelgid).[100]

These GE projects are seductive for those concerned with health of native forests and nostalgic for a time when these majestic trees lined our streets and graced public

Stretching from Maine to Mississippi and throughout eastern US forests, the American chestnut (*Castanea dentata*) was a keystone forest tree species for centuries. However, chestnut blight has almost entirely eliminated the American chestnut from the forest canopy. There are several projects to develop blight-resistant American chestnut trees through traditional breeding. The success of these projects demonstrates that GE techniques are not necessary to combat pathogens.

spaces. However, it is challenging to engineer durable, lasting resistance for the long life span of a tree such as the American chestnut. With crop breeding, scientists are satisfied if resistance to a fungal disease maintains its effectiveness for 20 to 30 years, but this time span is not sufficient for the American chestnut. Scientists engineering the American chestnut are experimenting with several genes from other species, alone and in various combinations, but it will take years to determine which are most effective against chestnut blight. Even then, what is effective in the short term may not provide the long-term protection needed.

In addition, ecological consequences of fungal resistance traits will be difficult to test because so little is known about the American chestnut's normal ecological interactions which are likely to be specific to a site or region. For example, how do these genes affect other beneficial and pathogenic fungi and bacteria?

The American chestnut produces an edible nut crop as well as wood. Although fruiting has not been allowed in the field tests, if the trees are eventually allowed to mature, food quality and safety for animals and humans will need to be assessed.

Finally, as noted earlier, there are several projects to develop blight-resistant American chestnut trees through traditional breeding. They are having some success, and developers are starting to plant experimental resistant trees in forests. These traditionally bred "restoration chestnuts" are also being planted in public spaces, including in the Bronx, where the first blighted trees were discovered in the early 1900s.[101] The success of these projects demonstrates that GE techniques are not necessary to combat pathogens.

Tree plantations, especially GE tree plantations, are no substitute for properly nurturing soil. Studies show that native forests provide regeneration of degraded soil, creating better soil characteristics than eucalyptus or other tree plantations.

ENVIRONMENTAL CONSEQUENCES OF GE TREES

Genetically engineered trees have various environmental consequences that will alter the ecosystems in which these trees are planted and can impact native forests if the transgenes spread. Below, we examine some of the potential detrimental impacts using GE eucalyptus plantations as an example.

SOIL QUALITY

Tree plantations negatively alter soil structure and degrade productive forest, farmland, and other ecosystems that are converted into plantations.

One primary way that plantations harm soils is from intensive use of pesticides and fertilizers. The plantation management practices recommended by ArborGen for freeze-tolerant eucalyptus (FTE) illustrate this. In order to maximize yields and shorten rotation periods, the company suggests a site preparation treatment of glyphosate to clear out any remaining weeds, an application of phosphate fertilizer at the time of seedling planting, further herbicide weed control applications in the first and second year after planting, and a nitrogen fertilizer application between the second and third year.[102] These harmful chemicals degrade soil and water quality both on- and off-site.

The chemical cycle is likely to be more frequent with GE eucalyptus plantations that are grown for biofuels because they will be harvested every three years, and after harvest, the cycle will repeat itself. ArborGen plans to replace many of the existing pine tree plantations currently in the southern part of the US with GE eucalyptus trees, and while conventional pine plantations are not ideal for soil conservation, they require far fewer chemicals, in part because pine plantations are usually harvested every 25 years compared to the GE eucalyptus' three years.[103]

Additionally, soil in eucalyptus plantations contains lower levels of organic carbon than do natural forests.[104] This indicates poor soil stability, which increases the likelihood of soil erosion. Erosion and chemical-intensive forestry practices may degrade land to the point where it no longer can sustain commercial tree plantations. This will result in a push to convert other land into plantations.

Tree plantations, especially GE tree plantations, are no substitute for properly nurturing soil. Studies show that native forests provide regeneration of degraded soil, creating better soil characteristics than eucalyptus or other tree plantations.[105]

CLIMATE CHANGE

Carbon sequestration is often touted as a benefit of tree plantations and GE trees; however, GE trees may actually increase carbon emissions and exacerbate climate change. In some instances, old growth forests store up to three times more carbon than a tree plantation.[106]

Carbon sequestration is often touted as a benefit of tree plantations and GE trees; however, GE trees may actually increase carbon emissions and exacerbate climate change. In some instances, old growth forests store up to three times more carbon than a tree plantation.

As noted, freeze-tolerant eucalyptus grown as a biofuel feedstock will be harvested every three years (seven years for pulpwood).[107] This period is too short to develop plantations into anything resembling mature forests with superior carbon storage capabilities. Also, GE tree plantations require high amounts of greenhouse gas-emitting chemicals, notably synthetic nitrogen fertilizer, which is responsible for around 60 percent of total global nitrous oxide emissions.[108]

INTENSIVE WATER USE

Intensively managed eucalyptus plantations negatively impact fresh water quality and supply. Studies in Argentina, Ethiopia, and elsewhere show that eucalyptus water uptake is greater than that of surrounding vegetation, including other forest trees.[109] And, as part of the environmental assessment for a field trial of GE eucalyptus, the US Forest Service (USFS) identified risks to water resources that could arise from high intensity GE eucalyptus plantations:

> *Our review of the literature and estimate of eucalyptus transpiration suggests that water use is at least 2-fold greater than most other native forests in the southeastern US. Stream flow will be about 20% lower in eucalyptus plantations vs. pine plantations. Planting eucalyptus hybrid plantations will lower the water table, and affect groundwater recharge and stream flow dynamics.*[110]

These detrimental impacts are bad enough in a region with an ample supply of water, but in the southeastern US, where GE eucalyptus will be planted, fresh water supplies are already scarce. Researchers now say that the southeastern US no longer has enough water capacity to meet its own needs.[111] Genetically engineered eucalyptus plantations will undoubtedly exacerbate water issues in this region. The USFS predicts that if GE eucalyptus invades native forests, water use will increase due to generally higher transpiration rates of invasive species over native species.[112] In sum, large-scale eucalyptus plantations will devastate water resources.

In the southeastern US, where GE eucalyptus will be planted, fresh water supplies are already scarce. Genetically engineered eucalyptus plantations will undoubtedly exacerbate water issues in this region.

ArborGen claims that the intense water usage by eucalyptus will be valuable in purposefully lowering water tables to counteract any potential groundwater salinity problems.[113] Although afforesting land with eucalyptus to lower saline groundwater has been a successful practice in Australia, it is not relevant in the southeastern US where soils are not saline.[114] In fact, groundwater levels in the Upper Floridian Aquifer are already so low that the aquifer is being inundated with saltwater in coastal areas.[115] Thus, planting eucalyptus could worsen salinity problems by lowering the water table, allowing seawater to further inundate valuable groundwater resources.

One of ArborGen's proposed methods to minimize hydrological impacts during field trials is to "manage stocking," i.e., to reduce the density of trees planted. The USFS points out that the primary objective of future GE eucalyptus plantations is to maximize the production of biomass, which will require the full stocking of tree stands; thus, managing stocking is not a practical solution on a commercial plantation.[116]

BIODIVERSITY

For many plant and animal species, tree plantations are unsuitable habitats. Studies indicate that lack of food, proper shelter, and germination sites result in lower levels of biodiversity.[117] In one study, Brazilian eucalyptus plantations were shown to support about a quarter of the number of bird and amphibian species compared to native primary forests nearby.[118]

Southern forests have a significant share of the flora and fauna found in the US. Almost 600 species of birds—over 90 percent of all bird species in the US—can be found in southern forests. These forests are also home to more than 130 tree species.[119] In contrast, Harvard biologist E.O. Wilson estimates that southern pine plantations contain 90 to 95 percent fewer species than natural forests.[120] ArborGen intends for GE eucalyptus to replace many conventional pine plantations; however, water intensive, fire-prone, and potentially invasive GE eucalyptus may be an even greater threat to biodiversity and endemic species than conventional pine plantations.

Plantations of eucalyptus will also affect native vegetation in the area. Eucalyptus trees exude chemicals into the soil that inhibit the growth of some competing vegetation, a phenomenon called allelopathy.[121] Also, eucalyptus trees deposit large amounts of leaf and bark litter on the forest floor that can work in tandem with allelopathic chemicals to restrict the growth of other vegetation that might otherwise provide valuable food and shelter for animals and insects. Plantation management practices, including eradicating undergrowth to reduce competition, will also limit biodiversity.[122]

For many plant and animal species, tree plantations are unsuitable habitats. Studies indicate that lack of food, proper shelter, and germination sites result in lower levels of biodiversity. In one study, Brazilian eucalyptus plantations were shown to support about a quarter of the number of bird and amphibian species compared to native primary forests nearby.

POTENTIAL INVASIVENESS AND TRANSGENIC CONTAMINATION

Eucalyptus species are native to Australia and parts of Papua New Guinea and Indonesia, but today are planted in over 90 countries worldwide.[123] While most alien eucalyptus species do not invade native habitats, there are notable exceptions. In California, both the Tasmanian bluegum (*Eucalyptus globulus*) and the redgum (*E. camaldulensis*) are classified as invasive.[124] In South Africa, *E. grandis*, one of the parent species of the hybrid used to create ArborGen's GE eucalyptus, is considered invasive.[125]

Within the proposed GE eucalyptus planting region in Florida, three eucalyptus species are now grown, including *E. grandis*.[126] The University of Florida's assessment of non-native plants concludes that *E. grandis* is predicted to be invasive in Florida and recommends specific management practices, including harvesting biomass before seeds are produced.

Proponents of GE trees claim that escape of transgenes from plantations will be insignificant because trees will be engineered to inhibit pollination and seed formation. However, in the case of ArborGen's freeze-tolerant eucalyptus, trees are engineered to lack pollen but still produce functional female structures. If compatible non-GE eucalyptus are growing nearby, pollen from these trees could fertilize the GE flowers. This would produce fertile seeds with GE traits. Also, habitat disturbances such as wildfires and extreme storm events may help GE trees establish in the wild by distributing seeds longer distances and creating more favorable conditions for them to germinate.[127] The frequency and intensity of such disturbances are expected to increase due to climate change.

Ultimately, the best predictor of whether a species may become invasive in a new habitat is whether it has become invasive elsewhere, but there are no historic data for these GE eucalyptus varieties. Woody plant species such as eucalyptus can take over 100 years to demonstrate invasive impacts, at which point irreparable damage may already have occurred.[128]

WILDFIRE RISKS

In many regions of the world, climate change is responsible for hotter and drier climates, a recipe for more frequent and severe wildfires. Some tree plantations will potentially promote wildfires or exacerbate impacts.

Eucalyptus trees are prone to catastrophic forest fires due to leaves rich in resins and volatile oils, highly flammable bark, and large amounts of litter buildup. Some varieties of eucalyptus are even dependent on forest fires in order to reproduce. For example, the mountain ash eucalyptus (*E. regnans*) seeds germinate more effectively when they drop on burned forest floor.[129]

In Australia, officials have long tried to manage the flammable eucalyptus forests with controlled burns to clear litter buildup below the trees. Yet under hot and dry conditions, massive fires can still strike.[130] In California, eucalyptus trees have been a factor in several forest fires, including the October 1991 Berkeley-Oakland Hills fire that destroyed 3,000 homes and killed 24 people.[131]

Eucalyptus trees are prone to catastrophic forest fires due to leaves rich in resins and volatile oils, highly flammable bark, and large amounts of litter buildup.

FUTURE OF GE TREES: SUSTAINABLE WAY FORWARD OR DANGEROUS DIVERSION?

Truly sustainable solutions involve farming and forestry practices that work with and conserve wild forests, wetlands, prairies, and other ecosystems.

> *It's through plantation forests and increased productivity that you protect native forests. We pursue products that we know are environmentally safe.*
>
> —BARBARA WELLS, FORMER CEO OF ARBORGEN[132]

Industry is marketing GE trees as the panacea for many of our intractable environmental problems: overexploitation of natural forests for wood products, dependence on fossil fuels, and climate change.

Industries claim that GE trees will satisfy demand for fuel, fiber, and lumber without having to cut down remaining natural forests or drilling for more oil, thus saving nature.[133] However, biotech industry claims about GE trees are based on flimsy scientific evidence and flawed understanding of economic drivers that harm forests and other ecosystems. In fact, experiences so far with high-yielding plantations and biofuel crops are not encouraging.[134] As the global demand for biofuels and wood-based products continues to increase, economic imperatives drive production further into forests and other ecosystems.

In order to assess whether this technology can deliver its marketing promises of protecting forests, mitigating climate change, and other claims, it is vital to undertake rigorous and long-term analyses. Truly sustainable solutions involve farming and forestry practices that work with and conserve wild forests, wetlands, prairies, and other ecosystems.

GENETICALLY ENGINEERED TREES—PROVIDING COVER FOR POLLUTING INDUSTRIES

When American chestnuts were kings of the forest,[1] "a squirrel could travel through America's chestnut forests from Maine to Florida without ever touching the ground."[2] Today, this is but a nostalgic memory. American chestnuts, *Castanea dentata*, were at one time the single most prevalent hardwood tree in the eastern half of the United States.[3] In the late 19th century, however, the chestnut blight-causing fungus, *Cryphonectria parasitica*,[4] eradicated about four billion majestic chestnut trees. The United States Department of Agriculture (USDA) recognizes chestnut blight "as one of the worst ecological disasters of the 20th century."[5] The fungus was imported via Asian chestnut saplings. To this day, few saplings survive the disease[6] and those chestnuts that remained became victims of deforestation.

Duke Energy, the largest electric power holding company in the US with major coal mining operations, is financing GE American chestnut development to stock tree plantations harvested for its wood pellet mills.[7] The wood pellets are used as co-firing biomass fuel, in conjunction with coal, natural gas, and other fuels, for electrical generating facilities. Emerging science reveals that burning trees to produce electricity can be at least as, and often more polluting than burning coal, gas, and oil.[8]

Paradoxically, Duke Energy, views GE American chestnuts as being "highly effective carbon-sequestering machines,"[9] and, together with the Forest Health Initiative (FHI), initiated a project to repopulate central Appalachia, notably, Duke's coal mountain top removal sites, with the GE American chestnut trees. The "reforestation" project, referred to by the *Economist* as "a quango set up,"[10] is part of Duke Energy's "ongoing initiatives to reduce or offset emissions." [11] Intriguingly, the project's goal to restore chestnut forests in 2015[12] coincides with the year that Duke Energy must comply with the Surface Mining Control and Reclamation Act of 1977 (SMCRA), an American federal law. The SMCRA mandates and enforces that coal-mining industries must restore abandoned mine lands.

Additionally, Duke Energy is receiving saleable certified carbon emission credits (CER) through the Clean Development Mechanism (CDM) for a project in Peru. Duke Energy's two hydro plants with a combined installed capacity of 16 megawatts on Peru's Chancay River were established in 2008.[13] Duke Energy can sell CERs earned from this project to carbon exchange markets or directly to utilities in industrialized nations to help them meet their carbon reduction targets.[14] Critics of the CDM, part of the Kyoto Protocol and international efforts to reduce greenhouse gas emissions, assert that the scheme provides mechanisms for companies such as Duke Energy to continue, or even expand, greenhouse gas emitting business as usual.

Nevertheless, for its efforts to restore Appalachian forests and reduce its environmental footprint Duke Energy earned its place on the Dow Jones Sustainability Index (DJSI), the first global indices tracking the financial performance of the leading sustainability-driven companies worldwide.[15]

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[3] Burhans and Hebard, supra note 1.

[4] The Economist, supra note 2.

[5] Burhans and Hebard, supra note 1.

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THE FIRST GENETICALLY ENGINEERED TREE LEGAL CHALLENGE

The US has yet to approve the commercial planting or sale of any GE forest trees. However, the Center for Food Safety (CFS) has already challenged the US Department of Agriculture's (USDA) approval of open-air, experimental field tests of the first GE trees proposed for future commercial approval, freeze-tolerant eucalyptus trees. The GE eucalyptus is a hybrid of *Eucalyptus grandis* and *E. urophylla*, engineered by the biotech forestry company ArborGen in an attempt to increase tolerance to cold temperatures. ArborGen intends to commercialize the GE eucalyptus and grow them in plantations in the southeastern United States for paper and biofuel production.

ArborGen originally sought commercial approval for these trees in 2008. In October 2009, the USDA notified ArborGen that its petition for commercial approval was flawed and insufficient and raised a number of issues that needed to be addressed. ArborGen subsequently submitted a revised petition for commercialization, which is still pending before the USDA.

In 2010, the USDA granted field trial permits to ArborGen allowing it to plant the GE eucalyptus tree in 28 locations, spanning seven southern US states (Alabama, Florida, Georgia, Louisiana, Mississippi, South Carolina, and Texas). The exact locations were claimed to be "confidential business information" and thus not disclosed to the public. The authorized 260,000 trees on 330 total acres represented by far the most extensive planting of a genetically engineered tree species anywhere in the United States. The GE eucalyptus trees would flower and spread pollen over seven years, risking their potential spread beyond the field sites. In addition to escape, CFS identified a number of dangers posed by the trees, such as the potential for contamination of non-GE trees, invasiveness, massive consumption of water, high flammability, and unknown impacts to wildlife species.

Due to these concerns and others, several thousand comments opposing the commercialization of the tree were submitted to the USDA, including comments from other government agencies, scientific experts, and officials. Nonetheless, the USDA approved the trials after only a cursory and disjointed review of their potential impacts and rejected proposals from CFS and others that it deny the permits outright; dramatically scale them back; or, at a minimum, undertake a rigorous review of their potential impacts under federal law and consult with other federal and state agencies before any approvals were granted.

Thus, on July 1, 2010, CFS filed the first-ever lawsuit on GE trees, challenging the USDA's approval of these unprecedented field trials. CFS initiated the case, along with Center for Biological Diversity, Dogwood Alliance, Sierra Club, the Global Justice Ecology Project, and CFS's sister nonprofit, the International Center for Technology Assessment. The Plaintiffs argued that the USDA violated the National Environmental Policy Act (NEPA), commonly known as our national charter for protection of the environment, by approving the field trials without undertaking a rigorous NEPA analysis, known as an Environmental Impact Statement (EIS). The Plaintiffs also argued that the USDA had violated the Endangered Species Act (ESA) by failing to consult with the wildlife expert agencies regarding the GE trees' potential impacts on protected species and their habitats. Both ArborGen and the Biotechnology Industry Organization intervened in the case in order to side with the USDA.

CFS litigated the case from July 2010 to October 2011. In May 2011, the Court ruled that the Plaintiffs had standing to challenge the field trials and ordered the parties to formal mediation. Mediation failed and the case proceeded. In October 2011, the Court ruled in the USDA's favor and against the Plaintiffs. However, the Court's decision was largely based on what it viewed as the relatively small scale of the field trials and approved of the USDA action by relying on justifications that would not apply to broader field tests, nor any proposed commercial approval that would allow for widespread plantings and their negative environmental impacts.

Since the case's conclusion in 2011, the USDA has not approved ArborGen's broader request for commercial approval. Instead, in February 2013, the USDA announced that it would undertake a full EIS under the NEPA before deciding whether to approve the GE trees. By so doing, the USDA acknowledged that the GE eucalyptus trees may have significant environmental impacts that the agency must rigorously analyze, at a minimum, before considering whether to allow their commercial planting and sale. It is likely that this unprecedented USDA decision was forced by the prior field trial litigation. (Prior to 2013, the USDA had never undertaken an EIS on a GE crop without being forced to do so by CFS through litigation.) The draft EIS is estimated to be released for public comment in late 2013 or 2014. The EIS process will provide important analysis of the environmental impacts of GE eucalyptus trees as well as shed light on how the USDA will approach GE tree oversight going forward.

CHAPTER THREE

WHAT'S PAST IS PROLOGUE[1]

Those who cannot remember the past are condemned to repeat it.
—GEORGE SANTAYANA, *Life of Reason*[2]

In assessing the potential impacts of transgenic trees, we can learn from the scientific and empirical experiences with genetically engineered (GE) crops. As an early adopter and the largest cultivator of GE crops, the US experience portends potential environmental and socioeconomic consequences of GE trees. Today, 93 percent of soybeans,[3] 94 percent of cotton,[4] 88 percent of corn,[5] and 90 percent of canola[6] in the US are genetically engineered. Despite fifteen years of commercialization, these crops have failed to deliver on biotech industry promises to reduce chemical use, decrease world hunger, ameliorate global malnutrition, or combat climate change.

In assessing the potential impacts of transgenic trees, we can learn from the scientific and empirical experiences with genetically engineered (GE) crops. As an early adopter and the largest cultivator of GE crops, the US experience portends potential environmental and socioeconomic consequences of GE trees.

Instead, biotechnology firms have delivered a handful of GE commodity crops that have one of two characteristics or *traits*: 1) herbicide resistance (HR), meaning they can withstand direct, repeated, and indiscriminate dousing of a broad-spectrum herbicide to kill nearby weeds; or 2) Bt-producing crops, meaning they produce endogenous pesticides that kill several insect species. These two traits account for virtually 100 percent of global biotech crop acreage.[7] Around 85 percent of GE crops are herbicide-resistant. In the US, the majority of these crops are resistant to a single herbicide: glyphosate. Glyphosate is the active ingredient in Monsanto's patented herbicide Roundup.

The US experience with GE crops over the last decade documents their myriad harms to the environment, public health, farmers, and rural communities. Here is an overview of a few of the troubling consequences of GE crops.

As superweeds overtake farm fields across the country, farmers are turning to higher concentrations of herbicides, more frequent spraying, and more toxic chemicals. As a result, pesticide use has significantly increased in the US over the last decade—not decreased as GE crop proponents suggest.

SUPER WEEDS, SUPER PROBLEM

Glyphosate is the most heavily used herbicide in the world due to widespread planting of Monsanto's Roundup Ready crops.[8] Agronomists around the globe are alarmed by the growing epidemic of "superweed" populations that have evolved resistance to glyphosate due to its increased use on glyphosate-resistant crops. According to a survey by Stratus Agri-Marketing, weeds resistant to glyphosate infested over 61.2 million crop acres in 2012—roughly equivalent to the size of Michigan—causing serious problems for nearly half of US farmers.[9] The survey also indicates that the rate at which glyphosate-resistant superweeds are spreading is gaining momentum, increasing 25 percent in 2011 and 51 percent in 2012.[10]

Leading weed scientists warn that farmers are "running out of options" to control what is rapidly becoming an "unmanageable problem."[11] Multiple tactics are used in attempts to eradicate the superweeds: applying higher doses of Roundup as well as additional toxic herbicides; soil-eroding tillage; and deploying massive crews to manually remove weeds. Such practices damage soil and water integrity and reduce profits for farmers who must spend more on weed control.[12]

In response to the superweed epidemic, agrichemical companies are developing the next generation of GE crops that are resistant to different and sometimes more toxic herbicides. For example, Dow AgroSciences is seeking USDA approval of corn and soybeans resistant to 2,4-D, an active ingredient in the Vietnam-era defoliant Agent Orange, which is often contaminated with carcinogenic dioxins. Likewise, Monsanto is seeking approval for transgenic dicamba-resistant soybeans and cotton. Dicamba has been linked to increased rates of colon and lung cancer in farmers.[13] Engineering resistance traits for these toxic herbicides will simply lead to superweeds that can withstand additional chemical applications rather than solve the problem of herbicide-resistant weed evolution.

INCREASED PESTICIDE USE

As superweeds overtake farm fields across the country, farmers are turning to higher concentrations of herbicides, more frequent spraying, and more toxic chemicals. As a result, pesticide use has significantly increased in the US over the last decade—not

decreased as GE crop proponents suggest. Comprehensive reviews by Washington State University professor Dr. Charles Benbrook on pesticide use as a result of HR crops reveal that upward of 26 percent more pesticides per acre were used on GE crops than on non-GE, conventional crops in 2008.[14] Altogether, GE crops are responsible for a 527 million pound increase in herbicide applications in the US between 1996-2011.[15]

The US experience with GE crops over the last decade documents their myriad harms to the environment, public health, farmers, and rural communities.

BATTLING BUGS OR PROMOTING PESTS?— INSECT RESISTANCE AND HARM TO NON-TARGET ORGANISMS

Insect resistance is the second major trait of GE crops. To date, all GE insect-resistant crops are Bt crops, which contain one or more of a series of genes that code for Cry proteins, taken from different strains of the soil bacterium *Bacillus thuringiensis* (Bt). Specific Cry proteins are toxic to particular classes of insects. For example, some Cry proteins kill moths and butterflies while others are specific for flies, beetles, or mosquitoes.

Non-GE Cry proteins from Bt spores are commonly used insecticides favored by organic farmers because they are highly effective for specific insects and have relatively low toxicity for other types of organisms. In contrast to natural Bt sprays and dusts that are applied a few times a year, Cry proteins in GE crops are produced in most cells of the plants and are expressed throughout the growing season. Constant exposure of insects to these Cry proteins in GE plants elevates the risk of target insects developing resistance to the insecticide.

For example, in the Midwestern US, Bt corn engineered to resist western corn rootworm (WCR) is rapidly losing effectiveness as Bt-resistant WCR populations are developing in response to the engineered Cry protein.[16] This is already leading to increased use of additional insecticides[17] and portends what will happen when insect pests eventually become resistant to other Cry proteins in corn and other Bt crops.

In addition to increased pesticide use, the Cry proteins themselves in Bt crops can potentially harm insects that are not plant pests (non-target insects), both within GE crop fields and in surrounding areas. For example, although controversial,[18] some studies show that Bt Cry1Ab toxin is harmful to larvae of the green lacewing, a beneficial predator that feeds on aphids and variety of other small insects.[19] Similarly, in some experiments, Cry1AB is lethal to immature stages of a ladybird beetle, commonly known as a ladybug, that eats aphids, scales and mites.[20] Many beneficial insects also are found on trees and could be adversely affected by Bt toxins incorporated into GE trees.

Surprisingly, Bt toxins can be carried far from GE crop fields with effects literally downstream. Studies in the cornbelt in midwestern US found corn pollen and crop residues—parts of stems, cobs, leaves—in almost all of the nearby streams, having been conveyed by wind and water during storms.[21] Most of these corn plants were GE Bt varieties, and both the plant residues and the water in many of the streams contained Cry proteins derived from the GE corn as long as six months after harvest.

Earlier lab studies showed that detritus from Bt corn fed to caddisflies, stream insects that are important in aquatic food webs, reduced their growth and increased their mortality.[22] This is one illustration highlighting the need to ensure that Bt crop assessments include impacts to streams and other waterways. Genetically engineered Bt trees have the potential to contribute a significant amount of Cry protein into the environment during their normal growth as leaves fall, roots exude substances or decay, bark sloughs off, pollen is shed, flower petals are blown away, and other such events. Thus, impacts on both terrestrial and aquatic organisms need to be carefully considered.

Forests may be particularly affected by harm to non-target insects from Bt trees. A diverse array of forest butterflies and moths are likely to be sensitive to Bt toxins. They function as both pollinators and as prey, providing an important food source for other wildlife such as birds and bats. For example, researchers concluded that spraying forests with conventional Bt toxin impacted the food supply of the black-throated blue warbler, resulting in reduced breeding activity by the birds and causing their rate of reproduction to fall below their rate of mortality, thus threatening their populations.[23] Just as spraying Bt toxins can disrupt forest ecosystems, harm from Bt and other insecticidal toxins incorporated into GE trees is likely to ripple through forest ecosystems.

TRANSGENIC CONTAMINATION—EFFECTS ON ECOSYSTEMS

Genetically engineered plants that escape from cultivation can fundamentally alter ecosystems by competing with wild species, and the novel genes and proteins in these GE plants can have potentially harmful impacts on other organisms. Also, some GE plants can hybridize with their wild relatives, altering the genetic and biochemical composition of plant populations in ways that affect how they function in the environment. Thus, GE crops raise the novel problem of biological and genetic "pollution" that multiplies over time, in contrast to chemical pollution that tends to dissipate.[24] Plant geneticist Dr. Norman C. Ellstrand describes the difference between managing chemical pollution and transgenic plants: "A single molecule of DDT remains a single molecule or degrades, but a single crop [with its transgenes] has the opportunity to multiply itself repeatedly through reproduction, which can frustrate attempts at containment."[25]

The assurances of ArborGen and other companies that their transgenic trees will be "confined" to cultivated areas are similar to GE crop industry claims. Repeatedly, and over many years, the GE crop industry and US regulatory agencies insisted that trans-

Genetically engineered plants that escape from cultivation can fundamentally alter ecosystems by competing with wild species, and the novel genes and proteins in these GE plants can have potentially harmful impacts on other organisms.

genic plants would never escape.[26] However, seeds from GE crops do escape into the environment, from field tests and from commercial production, where they sometimes establish feral populations (populations that survive without human intervention) and become weeds. Also, several GE crops cross-pollinate related plants, causing widespread transgenic contamination via gene flow from GE crops to related conventional or organic cultivars or wild species.[27]

There are several examples of GE crops escaping into the wild where they become feral and of transgenic contamination by pollination of feral or wild relatives of GE crops:

- Experimental glyphosate-resistant alfalfa has contaminated non-GE alfalfa seed stocks in western North America.[28]
- Feral canola populations with GE glyphosate resistance have established around the world wherever GE canola is grown. They are crossing with each other to produce transgene combinations not found in commercial varieties.[29] Additionally, GE canola has the potential to cross with several weedy relatives, creating new weed problems.[30]
- GE glyphosate-resistant bentgrass has spread by seed escape miles beyond field test sites in eastern Oregon, and has even formed hybrids by cross-pollination with wild species in different genera, spreading the transgene to other wild grasses.[31] These glyphosate-resistant wild grasses are becoming a serious weed problem along irrigation ditches and are difficult to control with standard herbicide regimes.
- Transgenes have also contaminated wild cotton populations in Mexico,[32] the place of origin of the major cotton species grown throughout the world today. Within 15 years of growing GE cotton in Mexico, transgenic contamination has spread hundreds of miles through wild cotton populations; the wild cotton includes almost all the traits from commercial GE cotton. These wild cotton plants have crossed with each other, resulting in new combinations of herbicide-, insect-, and antibiotic-resistance traits. In other words, these cotton plants have "stacked" transgenes into novel combinations without human intervention.
- In Hawaii, there is widespread transgenic contamination of feral papaya found in abandoned fields, roadsides, and other areas due to seed escape and cross-pollination. There is also transgenic contamination of non-GE cultivated papaya.[33]

In addition to potential ecological impacts when GE crops contaminate non-GE crops, significant economic harm for farmers and rural communities can result, as recently demonstrated with rice[34] and more recently with wheat.[35] In addition, if organic crops are tainted with GE traits, farmers can lose their certification, their customers, their markets, and their reputations.

From experience to date with GE crops, it is clearly very difficult for GE crops to co-exist with other types of agriculture and with other ecosystems. Transgenes from some GE crops pose contamination risks for non-GE farmers, reducing their market opportunities. Although growers can take steps toward reducing the risk of transgenic

Because of their special biological characteristics, GE trees pose an even greater risk of escape and transgenic contamination than do crops, with potential to cause more serious environmental consequences in forests as well as significant economic harm to fruit growers.

contamination, the vagaries of weather, uncertainties of pollinator behavior, unknown locations of feral plants, and ever-present human error conspire to ensure gene flow regardless of precautionary measures.[36] In addition, wild relatives of GE crops can be at risk of transgenic contamination with negative impacts for the environment.

Because of their special biological characteristics (see Chapter Two), GE trees pose an even greater risk of transgenic contamination than do crops, with potential to cause serious environmental consequences in forests.[37]

GE trees, as with GE crops, will potentially enhance the problems they purport to solve and create new, often unintended consequences.

FALSE PROMISES

Although the industry claims that these herbicide-resistant and Bt crops increase yields, the only independent study of their results, *Failure to Yield* by Doug Gurian-Sherman of the Union of Concerned Scientists, concluded that "GE has done little to increase overall crop yields."[38] The report reveals that 86 percent of increases in corn yields since the introduction of GE corn is attributable to advances in conventional breeding—not genetic engineering.[39]

Similarly, GE crop proponents claim that such crops are needed to respond to climate change. After decades of research and millions of dollars spent, only one crop purports to exhibit a climate change-ready trait: Monsanto's DroughtGard drought-tolerant corn. Yet, an analysis of company data and the USDA's crop assessment shows that the genetically engineered variety conveyed only "modest protection against moderate drought" and was not significantly better than conventionally bred drought-resistant cultivars.[40] Currently, there are no commercially approved GE crops with inherently higher yield potential, nutritional enhancement, or salt tolerance.[41] Finally, GE crops have not contributed toward mitigating greenhouse gas emissions. Instead, GE crops perpetuate an industrial agriculture model that uses chemicals that contribute to climate change. As already noted, claims that GE crops use fewer chemicals are false. And, GE crops depend on synthetic nitrogen fertilizers, which contribute around 60 percent of total global greenhouse gas emissions of nitrous oxide.[42]

* * *

As discussed more thoroughly in other chapters of this report, GE trees, as with GE crops, will potentially enhance the problems they purport to solve and create new, often unintended consequences. Based upon data and empirical evidence of GE crops, we can anticipate some of the same problems with GE tree plantations—increased chemical use and the resulting pesticide pollution of natural resources such as soil, water, air, and wildlife; weed and insect resistance; and transgenic contamination of other trees and native forests.

CHAPTER FOUR

POLICY RECOMMENDATIONS FOR GE TREES

The lack of current policy addressing GE crops and GE trees specifically could lead to innumerable environmental and socioeconomic harms. However, it also provides many opportunities and avenues for change.

Given the significant uncertainties surrounding GE trees and the wide-ranging ecological impacts of their potential release into the environment, CFS urges the following policy recommendations.

1. MORATORIUM ON GE TREE TRIALS AND/OR COMMERCIALIZATION

Place a moratorium on open-air field trials of GE trees and halt consideration of any future commercial approval until and unless the US Department of Agriculture (USDA):

Completes a Programmatic Environmental Impact Statement (EIS) on the program of GE tree regulation and oversight, including GE tree testing and possible commercial approval, and GE trees' significant environmental and intertwined socioeconomic impacts. The impacts analyzed in the EIS should include invasive colonization; escape from trials; effects on wildlife, including insects and protected species; impacts on native forest ecosystems; impacts on surface and groundwater use; and impacts on current forestry management practices on public and private lands.

Revises the GE crop regulations under the Plant Protection Act (PPA) (7 CFR §340) to create a separate regulatory section specific to GE trees. This section of the PPA must properly account for GE trees' novel risks and impacts separate and above those of GE crops or other GE organisms, such as requiring GE tree-specific data requirements. The regulations should also apply the entirety of the PPA to GE trees, including new limits on testing (prohibiting open air plantings) and requiring that any approval prevent and/or ensure that it does not cause ecological harms.

As part of both of the above processes, performs formal consultations with other federal and state agencies with relevant expertise. This should include the Environmental Protection Agency, the Fish and Wildlife Service, the Forest Service, the Bureau of Land Management, and state agencies that oversee environmental regulations, fish, game, and forestry. Where joint and overlapping oversight is appropriate or needed, memoranda of understanding between the agencies should plainly establish the responsibilities for each agency with regard to GE tree impacts and oversight.

These regulatory improvements are feasible without new statutory authority, simply requiring action by the USDA and other federal agencies under existing federal law. Such reforms would significantly improve current regulatory approaches; increase scientific knowledge, public awareness, and transparency regarding GE trees; and frame oversight-based GE tree-specific data. However, they would also require a dramatic shift in USDA philosophy and approach to GE organisms and GE trees—a threshold that may prove difficult to reach.

2. PASS NEW COMPREHENSIVE GE LEGISLATION AND/OR GE TREE-SPECIFIC LEGISLATION

There are no laws in the US that address GE organisms specifically. Instead, agencies regulate GE plants and animals under older laws crafted prior to current expressions and applications of genetic engineering. Legislation should be passed to address GE crops and GE trees explicitly. The new legislation should create a precautionary regulatory framework for GE organisms and a separate framework devoted to GE trees that addresses their unique characteristics. A model law could draw on the approach of the European Union and other nations. It could require the regulatory changes discussed in Recommendation 1 and finally provide a long-overdue statute addressing GE organisms.

There are no laws in the US that address GE organisms specifically. Instead, agencies regulate GE plants and animals under older laws crafted prior to current expressions and applications of genetic engineering. Legislation should be passed to address GE crops and GE trees explicitly.

3. AMEND THE PLANT PROTECTION ACT TO ADDRESS GE TREES

The main statute currently applied to GE tree regulation is the Plant Protection Act (PPA), the statute under which the USDA regulates GE plants generally. Amendments to the PPA could improve oversight in various ways explained in Recommendation 1, requiring GE tree-specific regulation and data and regulating GE trees based on their environmental and socioeconomic impacts.

4. PASS LEGISLATION ESTABLISHING LEGAL LIABILITY FOR HARM FROM GE TREES

Liability for harms resulting from transgenic material that escapes from field trials, spreads via future commercial development, or otherwise contaminates wild or cultivated trees should rest with the patent holder or entity conducting the trials. This option would aim to enact legislation requiring that the patent holders and developers of GE trees remain strictly liable for any environmental or property damage caused by their biotechnology products.

This option would incentivize biotechnology developers and businesses to take responsible steps to avoid escape, contamination, or other harms in order to avoid legal liability. However, such liability would not address the current systemic flaws of GE tree regulation as it attempts to remedy the effects without addressing the cause. Many environmental harms caused by GE trees are irreparable in nature once they occur and could not be remedied solely by monetary damages.

Liability for harms resulting from transgenic material that escapes from field trials, spreads via future commercial development, or otherwise contaminates wild or cultivated trees should rest with the patent holder or entity conducting the trials.

5. STATE-LEVEL PROHIBITIONS OR LIMITATIONS ON GE TREE TESTING AND/OR COMMERCIAL USE

Given the lack of adequate federal regulation of GE trees, individual states could enact legislation or amend existing state law to address the harms of GE trees and prevent their planting within their respective borders. For example, GE food labeling bills are currently active in dozens of states and have passed in several. State GE food labeling ballot initiatives are also active. However, while perhaps more likely to pass than federal legislation, this option would only protect a limited number of states.

6. COUNTY-LEVEL PROHIBITIONS OR LIMITATIONS ON GE TREE TESTING AND/OR COMMERCIAL USE

As previously noted, federal, state, or local governments have yet to adequately regulate GE trees in a manner that will prevent economic and environmental consequences. Several counties and cities in California, Hawaii, Washington, and Maine have already adopted ballot measures or county resolutions banning GE crops in their regions. As of the publication of this report, Santa Cruz, Mendocino, Marin, and Trinity counties and the City of Santa Cruz in California; Hawaii and Maui counties in Hawaii; San Juan County in Washington; and the Town of Montville in Maine have passed such initiatives and resolutions.[1] In these cities and counties, it is unlawful for any person to propagate, cultivate, raise, or grow some or all GE crops. Several other counties are currently in the process of proposing bans, and these efforts seem to be gaining momentum.[2] Similar county prohibitions could be enacted with regard to GE trees. However, while county-wide bans are more viable, the limited geographic scope of these bans makes for limited protection.

7. RESEARCH AND FUND NON-GE METHODS TO RESTORE TREE SPECIES AND FORESTS

Require mandates that prioritize alternative methods to restore native forests before applying GE tree technology. Funding for this research should focus on conventional breeding techniques that can improve disease resistance and other desirable traits. For example, American chestnut conventional breeding programs are showing promise for incorporating resistance to chestnut blight, eliminating the need for programs focused on GE blight resistance. These conventional alternatives should be fully researched before consideration of GE techniques because they show more promise for restoring tree species and maintaining the overall health of our native forests.

8. REVIEW AND REVISE THE US ENERGY POLICY ACT OF 2005 AND STATE ENERGY POLICIES

As outlined in this report, the US Energy Policy Act, and particularly the Renewable Fuel Standard (RFS), provides numerous incentives that stimulate and fund genetic engineering applications for biofuel, biomass, and other energy sources that may only exacerbate environmental crises and have negative socioeconomic consequences. Federal and state policies regarding tax credits and exemptions, grants, and loan guarantees should be revised to spur energy initiatives that are systemically sustainable over both the short and long term.

The US Energy Policy Act, and particularly the Renewable Fuel Standard (RFS), provides numerous incentives that stimulate and fund genetic engineering applications for biofuel, biomass, and other energy sources that may only exacerbate environmental crises.

Evidence of environmental and social harms due to current policies such as the biofuel mandate, as well as emerging scientific evidence questioning the sustainability of such programs, could mobilize citizen groups, opinion leaders, and legislators to reconsider federal and state policies. However, it will be difficult to challenge powerful, well-funded industry groups representing natural gas, coal, and oil companies, biotechnology corporations, and others that currently benefit from federal and state energy policies. Given this, a first step toward change would be to raise awareness about these policies among civil society, opinion leaders, the media, and legislators.

9. REVIEW INTERNATIONAL ENERGY AND CLIMATE AGREEMENTS AND POLICIES

International institutions, such as the World Bank and the UN Framework Convention on Climate Change, as well as trade agreements, can exert much more influence on issues such as GE trees than most people realize. Raising awareness about the links between domestic policies and international institutions can expose policies that propel GE tree development as well as mediate such actions. Additionally, engaging directly with these institutions provides a platform for countering false solutions and instead advancing more holistic, systemic remedies.

These arenas are powerful centers often under the radar of civil society; therefore, raising awareness of how they influence issues such as domestic energy policies can help actors craft solutions that address the full range of drivers promoting GE trees and plantations. However, effecting change within international forums can require long-term, sustained efforts.

Raising awareness about the links between domestic policies and international institutions can expose policies that propel GE tree development as well as mediate such actions.

* * *

The lack of current policy addressing GE crops and GE trees specifically could lead to innumerable environmental and socioeconomic harms. However, it also provides many opportunities and avenues for change. A combination of the above policy recommendations that revise old legislation, create new legislation, and function at local, state, federal, and international levels is critical to ensure that GE trees are appropriately tested and analyzed before any further field trials are undertaken or any commercial approval is considered.

APPENDIX ONE

GENETICALLY ENGINEERED TREES IN THE US: PETITIONS FOR APPROVAL

CROP	PHENOTYPE(S) (Traits)	PETITIONER	STATUS	YEAR APPROVED
Eucalyptus	Freeze-Tolerant, Fertility Altered	ArborGen	Pending	—
Apple	Non-Browning	Okanagan Specialty Fruits	Pending	—
Papaya	PRSV[1]-Resistant	University of Florida	Approved	2009
Plum	PPV[2]-Resistant	USDA/ARS	Approved	2007
Papaya	PRSV[1]-Resistant	Cornell University	Approved	1996

[1] Papaya Ringspot Virus
[2] Plum Pox Virus

Source: APHIS Notification, Permit, and Petition Data. Biotechnology Regulatory Services, APHIS, USDA. Last updated June 21, 2013. Accessed June 24, 2013. Available online at http://www.aphis.usda.gov/biotechnology/status.shtml.

APPENDIX TWO

CURRENT GENETICALLY ENGINEERED TREE FIELD TRIALS IN THE US

TREES	STATES	TRIALS	ACRES
Poplars	AL, AZ, GA, IN, KS, MN, MS, NC, OR, SC, TN, VA, WA	25	322.29
Eucalyptus	AL, FL, LA, MS, SC, TX	12	355
Citrus Trees	FL, TX	11	147.58
American Chestnut	GA, NC, NY, VA	8	18.8
Apple	CA, NY, WA, WV	7	26.04
Loblolly Pine	AL, FL, GA, SC	5	150.15
Walnut	CA	3	6.48
Sweetgum	GA, OR, SC	2	6
American Elm	NC, NY	2	3
European Plum	WV	1	4
Banana	HI	1	1.5
Papaya	HI	1	0.33
TOTAL	**20 STATES**	**78**	**1,041.17**

Source: APHIS Notification, Permit, and Petition Data. Biotechnology Regulatory Services, APHIS, USDA. Last updated June 21, 2013. Accessed June 24, 2013. Available online at http://www.aphis.usda.gov/biotechnology/status.shtml.

APPENDIX THREE

ORGANIZATIONS ACTIVE ON GENETICALLY ENGINEERED TREES (partial list)

Biofuel Watch	www.biofuelwatch.org.uk
Center for Biological Diversity	www.biologicaldiversity.org
Center for Food Safety	www.centerforfoodsafety.org
Dogwood Alliance*	www.dogwoodalliance.org
EcoNexus	www.econexus.info
Forest Ethics*	www.forestethics.org
Forest Guild*	www.forestguild.org
Global Forest Coalition	www.globalforestcoalition.net
Global Justice Ecology Project* (Stop GE Trees Campaign)	globaljusticeecology.org/stopgetrees.php
Institute for Social Ecology Biotechnology Project*	www.social-ecology.org/projects/biotechnology-project
Klamath-Siskiyou Wildlands Center*	kswild.org
NW Resistance Against Genetic Engineering*	www.nwrage.org/category/topics/genetically-engineered-trees
Polaris Institute*	www.polarisinstitute.org
Rainforest Action Network*	www.ran.org
Sierra Club*	www.sierraclub.org/biotech/trees.aspx
Southern Forests Network*	www.southernsustainableforests.org
World Rainforest Movement	www.wrm.org.uy
World Watch Institute	blogs.worldwatch.org/nourishingtheplanet/tag/ge

* Member of the Stop GE Trees Campaign

APPENDIX FOUR

MAJOR ACTORS—DEVELOPERS & FUNDERS OF GENETICALLY ENGINEERED TREES (partial list)

INDUSTRY

ArborGen

Duke Energy

Edenspace Systems Corporation

Futuragene
(subsidiary of Suzano Papel e Celulose)

GreenWood Resources

International Paper Company

MeadWestvaco

Monsanto Fund

Okanagan Specialty Fruits

Rubicon Ltd.

Southern Gardens Citrus

U.S. Sugar Corporation

Weyerhaeuser

GOVERNMENT AGENCIES

Advanced Research Projects Agency-Energy
[US Department of Energy (DOE)]

Biomass Research and Development Initiative
[joint DOE and US Department of Agriculture (USDA)]

US Department of Transportation

DOE Joint Genome Institute

Office of Surface Mining Reclamation and
Enforcement [US Department of the Interior]

USDA Agriculture and Food Research Initiative

USDA Agricultural Research Service

US Forest Service

UNIVERSITIES

Cornell University

Clemson University

Mississippi State University

North Carolina State University

Oregon State University

Pennsylvania State University

Purdue University

State University of New York College of
Environmental Science and Forestry

Texas A&M University

Washington State University

University of California Davis

University of Florida

University of Georgia

University of Hawaii Manoa

University of Washington

Virginia Tech University

NONPROFIT ORGANIZATIONS

The American Chestnut Foundation

Biofuels Center of North Carolina

Fagaceae Genomics Web

Forest Health Initiative

Institute of Forest Biotechnology

National Hardwood Lumber Association

Northern Nut Growers Association

US Endowment for Forestry and Communities

Wild Turkey Federation

ENDNOTES

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CHAPTER THREE: WHAT'S PAST IS PROLOGUE

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CHAPTER FOUR: POLICY RECOMMENDATIONS

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