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A ROADMAP FOR POPLAR AND WILLOW TO PROVIDE ENVIRONMENTAL SERVICES AND TO BUILD THE BIOECONOMY

The Roadmap is the lead document for a series of six Environmental Applications:

TB53E Poplar for Biosolids Management
TB54E Potential for a Poplar Industry Using Recycled Water
TB55E Willow Buffers in Agricultural Systems
TB56E A Willow Vegetative Cover in New York State
TB57E Shrub Willows for Living Snow Fences
TB58E Short-Rotation Coppice Willow in Ireland

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A ROADMAP FOR POPLAR AND WILLOW TO PROVIDE ENVIRONMENTAL SERVICES AND TO BUILD THE BIOECONOMY

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Executive Summary

Poplar (*Populus* spp.) and willow (*Salix* spp.) are fast-growing trees and shrubs that can be used for a wide variety of environmental remediation and management purposes as well as provide biomass for bioenergy and bioproducts. Recent research in the U.S. has focused on growing these trees as short-rotation woody crops to provide biomass for renewable fuels and bio-based chemicals and products; however, domestic bioenergy markets have been inconsistent and the industry is still emerging. Although both poplar and willow have a long history of use for a variety of environmental purposes and bioenergy in Canada, Ireland, and other European countries, many barriers exist to similar implementation in the U.S. In April 2016, a National Working Forum was held in Portland, OR, to discuss how to bring together the environmental uses of poplar and willow with the production of biomass for fuel. This paper provides a summary of information and recommendations derived from the Forum including: (1) benefits, both environmental and otherwise, of growing poplar and willow and opportunities for using the biomass from these plantings, (2) barriers to this new endeavor, and (3) solutions to link biomass from poplar and willow grown for environmental applications to bioenergy markets. While use of poplar and willow for environmental benefits and biomass utilization is limited in the U.S., there have been successful programs, which are discussed in the Roadmap's supplemental Environmental Applications Series.[1]

The Forum was organized and sponsored by three USDA National Institute of Food and Agriculture (NIFA) funded research projects. These regional projects have been conducting research to produce sustainable and renewable transportation biofuels and bioproducts from bioenergy crops, including poplar and willow. A wide variety of stakeholders attended the Forum, including experts and current practitioners using these trees for environmental applications, project researchers, and entrepreneurs. The Environmental Applications Series demonstrates how willow has been grown successfully on marginal and degraded lands in New York. Other examples show how poplar has been used to manage biosolids in Oregon and how willow is used as a buffer to contain nutrients leaching from agricultural fields in the Midwest. Growing biomass for energy production is only one possible use for these trees and shrubs; many others remain untapped or unexplored. The potential economic benefits are significant, especially in rural areas.

Despite the great possibilities of using poplar and willow for bioenergy, remediation, and wastewater treatment, there are many barriers including

[1] The title of this publication will be referenced simply as "Roadmap" in running text, throughout.

inconsistent markets and policies and lack of awareness for the uses of poplar and willow. Both government officials and potential practitioners are often unaware of the environmental services provided by poplar and willow. Additionally, perennial crops like poplar and willow can create management and economic uncertainties for growers, particularly with multi-year rotations of three to 12+ years. From the point of view of poplar and willow as a biofuels feedstock, there are demand and supply-chain challenges. Petroleum prices, which are currently low, are also a barrier towards adoption. Finally, policy support has been uneven, and policies favorable to bioenergy are typically shorter-term promotions or tax breaks. As such, investors may find it too risky to commit to longer-term investments.

Solutions to these barriers include market development for ecosystem services, consistent long-term policies, alternative wood products markets, regulatory and financial support, and consumer awareness and demand. Policies that are more aligned with the goals and objectives of poplar and willow for bioenergy and ecosystem services, and developing markets for those services, are critical. Applicable policies do exist in some states, and, at present, seeking state support may be the best road forward. Economic viability will rely on stable markets, both for ecosystem services and marketable biomass. Combining the incentives created through ecosystem services and low-carbon fuel markets could increase the economic viability of making bioenergy from poplar and willow, while addressing many environmental problems. A poplar- or willow-based system has the potential to be advantageous for landowners and others throughout the supply chain. This paper provides guidance towards the development of poplar and willow for environmental applications as well as a source of biomass for bioenergy.

Environmental Applications Series

TB53E Poplar for Biosolids Management

TB54E Potential for a Poplar Industry Using Recycled Water

TB55E Willow Buffers in Agricultural Systems

TB56E A Willow Vegetative Cover in New York State

TB57E Shrub Willows for Living Snow Fences

TB58E Short-Rotation Coppice Willow in Ireland

"The potential economic benefits are significant, especially in rural areas."

A ROADMAP FOR POPLAR AND WILLOW TO PROVIDE ENVIRONMENTAL SERVICES AND TO BUILD THE BIOECONOMY

Introduction

Poplar (*Populus* spp.) and willow (*Salix* spp.) are two genera in the Salicaceae family of fast-growing trees and shrubs that grow naturally throughout most of the temperate regions, and they can be used for a variety of purposes. Both have a long history of environmental application (e.g., **wastewater** management and buffers) as well as providing useful **biomass** for a variety of markets. Current research is focusing on growing these plants as **short-rotation woody crops** to provide biomass for **renewable energy**, **bio-based chemicals**, and **bioproducts** to build the **bioeconomy** (U.S. Department of Energy 2016).

In April 2016, a National Working Forum (hereafter Forum) was held in Portland, OR to discuss how to incorporate the environmental applications of poplar and willow in the expanding U.S. bioeconomy, where poplar and willow would be converted to fuels and chemicals to replace products that currently derive from petroleum. This combination is not unprecedented (Licht and Isebrands 2005). Poplar and willow are grown for environmental purposes and **bioenergy** in Canada, the United Kingdom, Ireland, and other European countries. The Forum was organized and sponsored by three USDA National Institute of Food and Agriculture (NIFA) funded research projects: Advanced Hardwood Biofuels Northwest (AHB), Integrated Biomass Supply Systems (IBSS), and Northeast Woody/Warm-season Biomass Consortium (NEWBio). All three of these projects did the critical research and development needed to produce sustainable and regionally-sourced transportation biofuels and bioproducts from either poplar or willow biomass. AHB focused on poplar as the bioenergy **feedstock** of choice for the Pacific Northwest, IBSS worked on poplar and energy grasses in the Southeast, and NEWBio looked at willow and other energy crops in the Northeast.

A wide variety of stakeholders attended the Forum including experts and current practitioners who are using poplar and willow for environmental applications and researchers from AHB, IBSS, and NEWBio. The goal was to determine how to incorporate the environmental uses of poplar and willow with the production of biomass to fuel a new bioeconomy (Figure 1). This roadmap is based on workshops, conversations, and presentations that occurred during the Forum and other related meetings and events. This publication outlines:

- **Benefits** of growing poplar and willow
- **Opportunities** for using the biomass from environmental plantings for a new bioenergy and bioproducts industry
- **Barriers** in this new endeavor
- **Solutions** to bridge the gap between growing poplar and willow for environmental applications and the creation of a bioeconomy sustained by poplar and willow feedstocks

"Poplar and willow are grown for environmental purposes and bioenergy in Canada, the United Kingdom, Ireland, and other European countries."

I) BENEFITS OF POPLAR AND WILLOW AND POTENTIAL OPPORTUNITIES

Benefits and Opportunities Overview

Poplar and willow have been used for thousands of years for a variety of purposes and products, such as pulping fibers, willow baskets, farm tools, engineered construction materials, and medicinal products (Gordon 2001). They are some of the most effective plants for **phytoremediation**, cleaning up a wide range of contaminants in soil, sediments, and water (Pilon-Smits 2005). Species of poplar and willow are currently being studied for their potential to provide biomass for a myriad of products including bioproducts, traditional wood products, and bioenergy in the form of heat, power, and transportation fuels. Growing poplar and willow as short-rotation woody crop for bioenergy can help protect human health and the environment by providing **ecosystem services** in multiple capacities.

As bioenergy crops, poplar and willow are often overlooked because the additional benefits they create are not given monetary values. Integrating biomass and environmental markets can create economic opportunities for communities, landowners, and growers, and make bioenergy crops viable. Rural communities in need of more economic-development opportunities are especially likely to benefit from new agricultural jobs, local energy production, as well as improved environmental conditions (Johnson and Altman 2014).

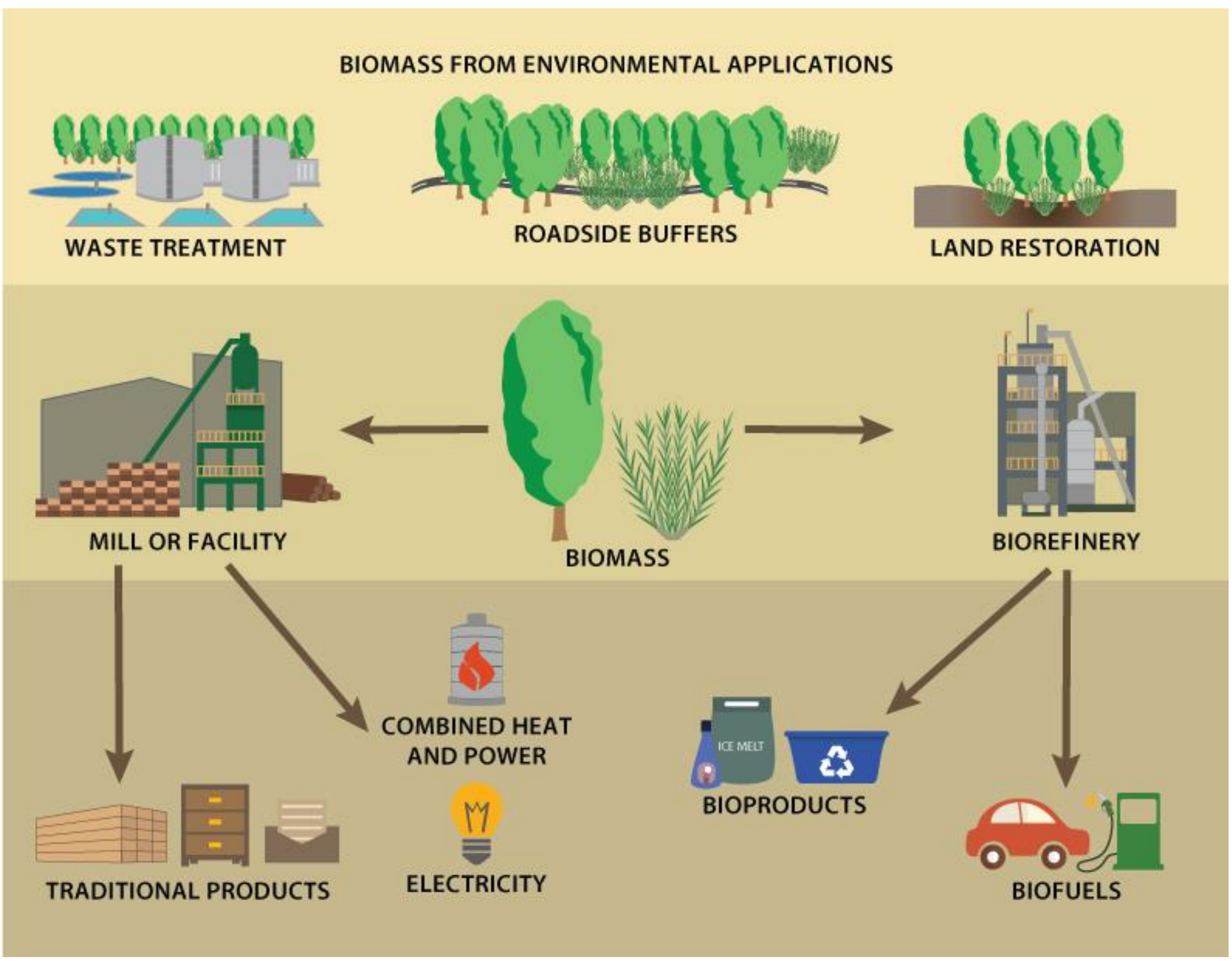


Figure 1. Using this system, poplar and willow would be grown for various environmental applications and then used as a biomass feedstock for numerous products within the bioeconomy.

Poplar and willow can be grown in many conditions and areas. **Marginal land** that may be considered less desirable for agriculture, or areas that border agricultural fields, would be suitable for poplar and willow. Plant characteristics, such as high growth rate, high biomass production, **coppice** ability, and tolerance of high-planting density, make poplar and willow ideal choices for multifunctional systems that can include biomass, **land reclamation**, phytoremediation, and **bioengineering** (Kuzovkina and Volk 2009). Poplar and willow's rapid growth rate, attributed to their high leaf area and extensive root system patterns, makes them particularly well-suited for environmental applications.

When poplar and willow are generated by coppice, multiple stems sprout back after harvest. Coppicing is a silvicultural technique where the trees and shrubs are cut and then regrown from the stump, sending off multiple stems (Figure 2). When managing the plants as a coppice, harvests will typically occur after two to four years of growth. Coppicing is an ideal management technique when high biomass yields are sought, rather than tall straight trees. Compared to traditional agricultural crops, short-rotation woody crops save replanting costs and increase carbon storage, contaminant uptake, biodiversity, and subsequent biomass production. When used for phytoremediation treatments, coppicing is advantageous because you can remove contaminants stored in the wood from the site more frequently (Baum et al. 2009).

Figure 2. Both poplar (left) and willow (right) sprout back multiple stems after cutting, which is known as a coppice.

Short-Rotation Woody Crops

Poplar and willow grown for less than 15 years are considered short-rotation woody crops. However, there are different terms used to describe the management practices used to grow these crops. Willow is mostly grown on coppice rotations of two to four years and is often called shrub willow. Poplar is most commonly grown for longer rotations of eight to 15 years, but can be grown on shorter coppice rotations as well. Since poplar and willow are primarily grown on marginal land using agricultural practices, some in the agricultural community might refer to poplar and willow as long-rotation crops or woody perennial crops. To reduce ambiguity and to remain consistent with academic literature, this roadmap considers poplar and willow to be short-rotation woody crops. However, we will occasionally differentiate between short coppice rotations (less than four years) and longer non-coppice rotations (4 to 15 years).

Benefits and Opportunities Summary

Environmental

Integrated land use and ecological restoration:

- Use marginal and idle land productively
- Restore former industrial sites and degraded lands
- Create riparian buffers for flood control, stream habitat improvement, and erosion reduction
- Generate wildlife habitat for birds, pollinators, and other species

Managing pollutants:

- Manage wastewater, biosolids, and stormwater
- Reduce non-point source pollutants, such as fertilizer runoff
- Sequester carbon
- Manage landfill leachate
- Control odors from feedlots and poultry houses

Social and Economic

Social benefits:

- Provide recreational, aesthetic, and cultural opportunities
- Rehabilitate urban brownfields and de-vegetated areas
- Enhance urban aesthetics and amenities
- Reduce community carbon footprint

Economic potential:

- Source local biomass and energy
- Increase energy security
- Provide market potential for renewable energy
- Expand markets opportunities for poplar/willow biomass
- Develop boutique and niche markets
- Monetize reduction in water pollution

Multiple diverse end products:

- Renewable transportation fuels
- Green bio-based chemicals and bioproducts
- Sustainable/responsible wood products

Environmental Applications, Benefits, and Opportunities

Tree and shrub planting is generally beneficial to the environment. Trees provide ecosystem services through water filtration, carbon sequestration, erosion control, shade, improved soil quality, and wildlife habitat. As perennial crops, poplar and willow store carbon taken in from the atmosphere as carbon dioxide. Even after harvest, they sequester carbon below ground in their well-established root systems. For example, studies have shown that willow can store about five tons of carbon per acre in its root system (Pacaldo et al. 2012).

Poplar and willow can restore contaminated land, including industrial sites and mined lands; they also benefit riparian areas and wildlife and help to manage wastewater, **biosolids**, and stormwater. Other uses include wind breaks, floodplain and waterway protection, and reduced nutrient loading (Isebrands et al. 2014). The supplemental Environmental Applications Series, and numerous other projects across the U.S., provide examples of these services (Figure 3).

Trees and shrubs can provide direct remediation benefits, which is an important, ongoing task. Many degraded lands persist in highly visible urban areas or areas adjacent to where people live and could create opportunities for urban forestry. While remediation is the primary task for which these trees can be planted, they also provide urban tree cover, reduce heat island effects, and beautify the landscape, thus improving the **viewshed** of the area.

The positive impact trees have on the viewshed provides major public health benefits (Donovan et al. 2013). Poplar and willow plantings, when grown on longer rotations, can provide a "park-like experience" within a city or adjacent to a suburban community. This urban forestry approach has been used successfully in the Midwest where hybrid poplar trees were planted to clean the soil and address **urban blight** (Kimes 2016).

Land Restoration

Poplar and willow are especially well-suited for improving soil and water quality and increasing the productivity of marginal land (Isebrands et al. 2014). Across the U.S. there are abandoned crop lands and other lands that could be restored by growing poplar or willow, which could also provide renewable energy feedstocks (Table 1). Research as part of the AHB project has shown that poplars grown as a bioenergy crop can remove boron from the soil when present at high levels and adjust the salinity, contributing to the restoration of land for traditional agriculture or other uses (M. Coleman pers. comm. 2017).

Considerable segments of land have been used for mining, landfills, or other industrial uses, turning them into **brownfields** or superfund sites. To return the land to a healthy and useable condition requires remediation and restoration to prevent the spread of contaminants. Some of these areas may be treated by removing contaminated topsoil and burying it elsewhere, or using a **geomembrane** or compacted clay cap that acts as a barrier to prevent water from entering the site, which protects groundwater from the contaminant.

Table 1. In the U.S. there are many opportunities for poplar and willow to utilize and restore degraded and abandoned lands.

Land Opportunity	Area (acres)	Biomass Energy Potential (GWh)
Abandoned Crop Land	168,668,944	1,784,474
Road Right of Ways	3,763,168	34,930
Abandoned Mine Lands	2,812,059	26,852
EPA Sites	11,631,250	40,924

Adapted from Milbrandt et al. 2014.

*EPA Sites include Brownfield, Federal/Non-Federal Superfund, and Resource Conservation and Recovery Act lands. This data is for the continental U.S. only and excludes Alaska and Hawaii.

> “Species of poplar and willow are currently being studied for their potential to provide biomass for a myriad of products including bioproducts, traditional wood products, and bioenergy in the form of heat, power, and transportation fuels.”

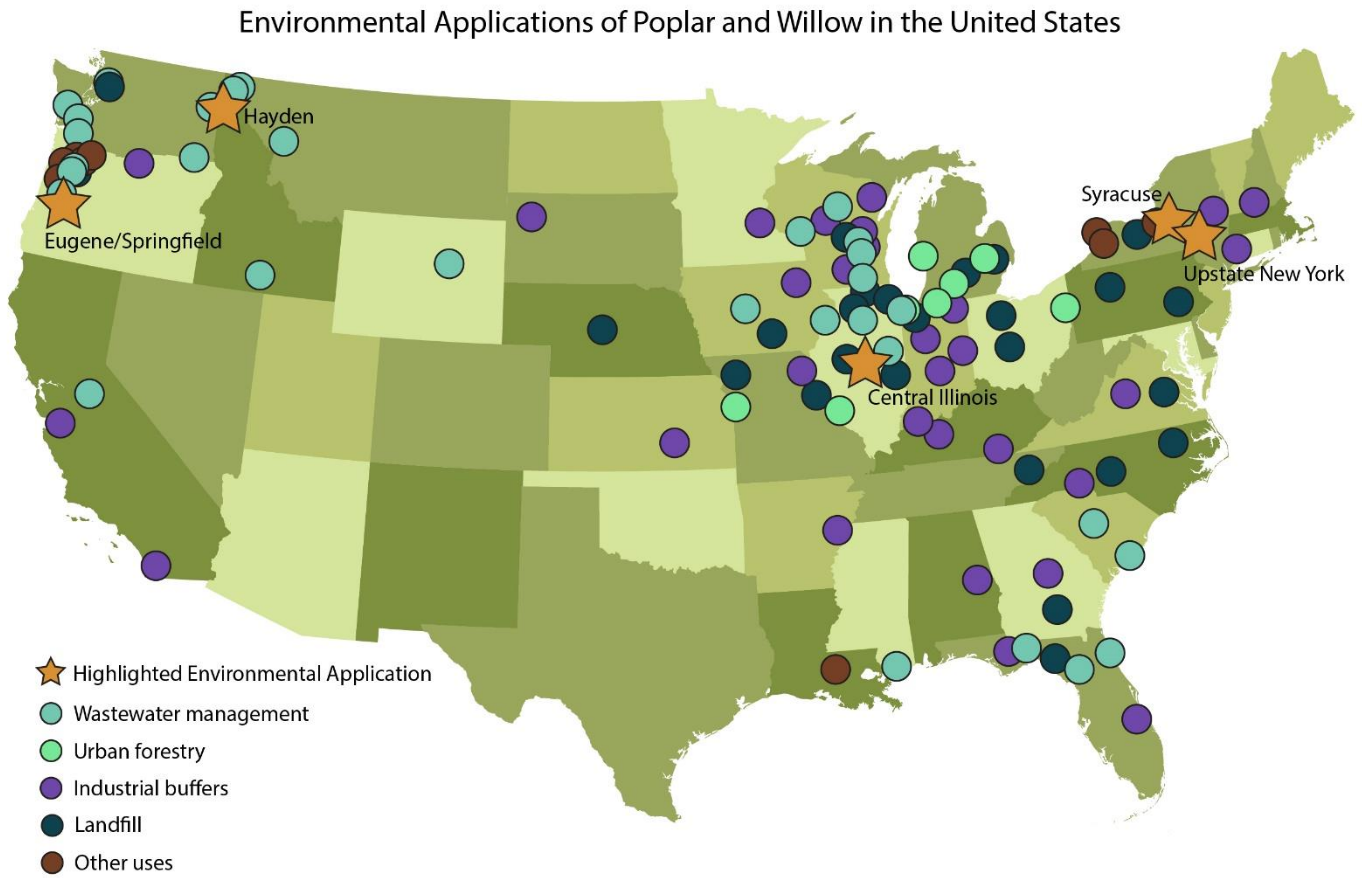
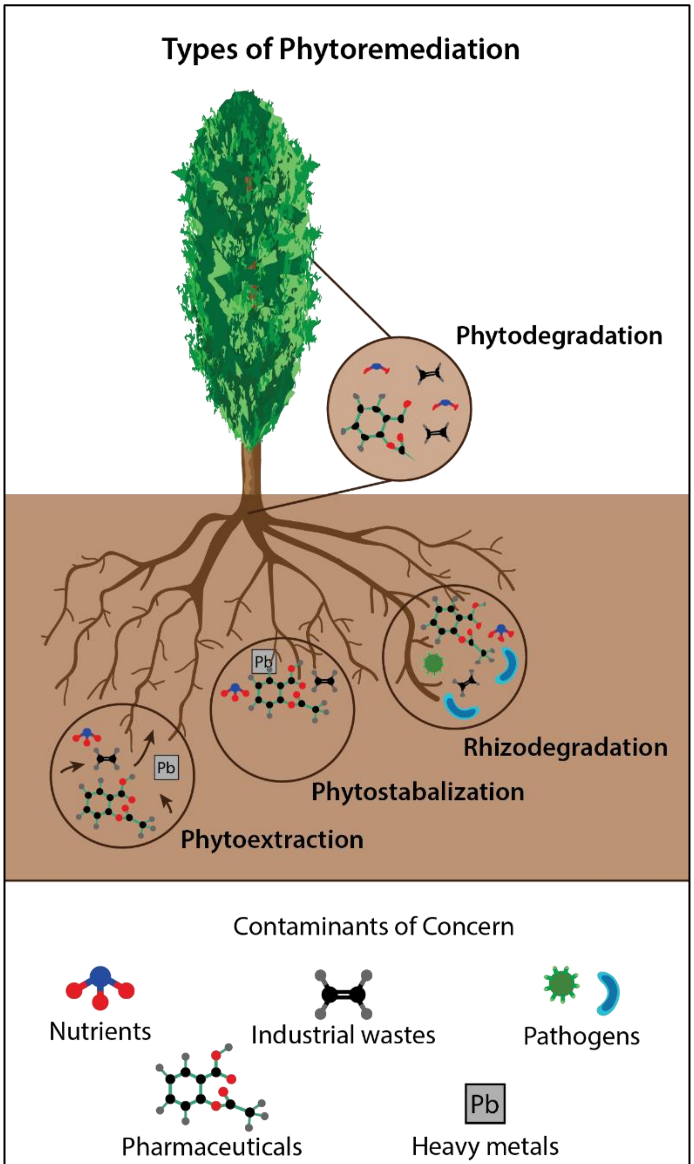


Figure 3. The locations of the referenced environmental applications (starred) and other poplar and willow environmental plantings across the United States. [Ecolotree Inc.](#) has implemented many of the landfill covers and buffer systems using both poplar and willow.

To remediate certain sites, a less expensive and intensive treatment includes planting willow or poplar. Phytoremediation is a process where plants are used to remove, transfer, stabilize, or destroy contaminates in the soil (Figure 4). Poplar and willow have the ability to absorb various chemicals while offering environmental benefits, such as soil erosion control, carbon sequestration, and wildlife benefits (Licht and Isebrands 2005). The trees remove the contaminants from the soil by biomass sequestration, chemical breakdown, and atmospheric volatilization. The trees or biomass can be removed and properly disposed of, or directly processed and utilized for bioenergy or bio-based chemicals. TB56E Developing a Vegetative Cover Using Shrub Willow (*Salix* spp.) in New York State provides a detailed example of a project in upstate New York where the potential negative impacts of a site with high levels of calcium and magnesium salts are being minimized using shrub willow.

Research by Doty et al. (2017) in California focused on using endophytes for phytoremediation. Endophytes are naturally occurring microorganisms that live symbiotically in the tissue of plants, including poplar and willow. This research found that by partnering poplar with a native endophyte, the use of poplar to degrade trichloroethylene (TCE) through phytoremediation was improved. With the high cost of engineering-based remediation technologies, this plant-microbe partnership is proposed as a strategy for responding to the thousands of TCE-contaminated sites around the world.



Phytoremediation—using plants to remove and control environmental contaminants

Phytodegradation—breaking down or transforming contaminants (in plant tissue)

Rhizodegradation—microbial breaking down of root zone contaminants

Phytostabalization—immobilizing root zone contaminants

Phytoextraction—hyperaccumulating soil contaminants in plant tissue

Figure 4. Phytoremediation includes many processes where **contaminants of concern** are either immobilized or broken down in the soil or absorbed by the roots of plants, such as poplar and willow (Tangahu et al. 2011).

Riparian Areas and Wildlife

Poplar and willow naturally thrive in riparian areas, and their use for stream protection is unparalleled. Strategic planting of poplar and willow along stream corridors in an agricultural area can reduce the amount of runoff nutrients from manure and fertilizer into streams. Manure also contains harmful pathogens, which could move into waterways. Since nutrient and pathogen runoff is a significant issue for waterways, planting poplar and willow in these areas provides a means for intercepting runoff and protecting water quality (Marron 2015). Even during winter dormancy, these trees have been shown to be effective at reducing nutrients and other contaminants in water (Aronsson 2001). Poplar and willow can also metabolize toxic chemicals such as atrazine, which is a widely used herbicide (Burken and Schnoor 1997). TB55E Willow Buffers in Agricultural Systems: Linking Bioenergy Production and Ecosystem Services describes a willow buffer system designed for capturing nutrient runoff from agricultural fields in the Midwest.

Poplar and willow have been shown to increase the abundance of small mammals and native song birds. Research has shown poplar to have a generally positive effect on wildlife in comparison to nearby agricultural fields (Zalesny et al. 2016a). Willow produces an abundance of flowers in early spring before most other plants bloom, providing a valuable early food source for bees and other pollinators. Poplar and willow are also known for attracting deer, turkeys, and other game (Figure 5), an important benefit for many rural landowners.

Wastewater and Biosolids Management

Wastewater treatment is a critical and costly service necessary for most municipalities and it is gradually becoming more expensive. It is common to use or add advanced treatment technologies to remove unregulated contaminants of emerging concern and to meet environmental requirements, such as **total maximum daily loads** (TMDLs). The amount of a specific pollutant that can be discharged into a water body is quantified by the TMDLs to ensure that the water body meets water quality standards.

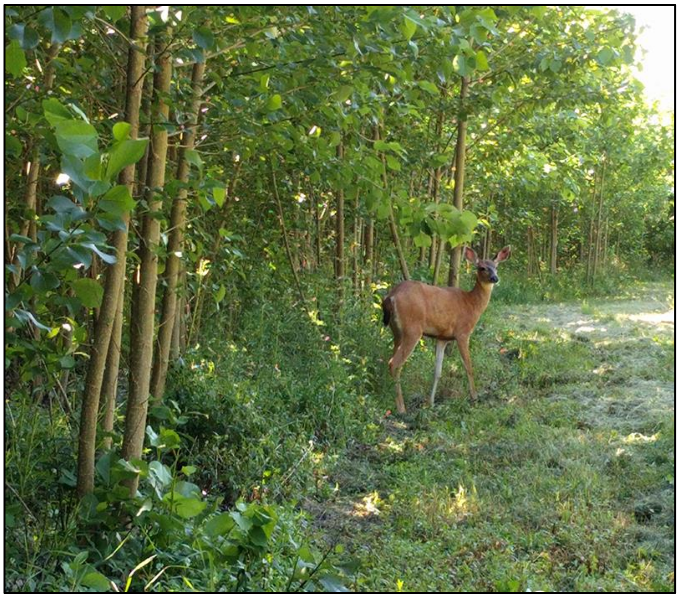


Figure 5. Rural landowners could generate additional revenue from their land by allowing hunting for deer and other game.

Very low levels of ammonia, phosphorous, copper, fire retardants, personal care products, and pharmaceuticals are among chemicals or elements of concern for long-term aquatic health.

Poplar or willow plantings can be irrigated with partially treated wastewater as a beneficial and appropriate alternative to traditional treatments. Applying **recycled water** to poplar and willow farms reduces the treatment facilities' economic and ecological costs associated with treating the wastewater (Zalesny et al. 2016b). The plants absorb both the water and the nutrients and can metabolize, uptake, or immobilize potential contaminants such as pharmaceuticals and metals. In addition, discharging warm recycled water into river systems can increase the river's temperature to levels that are considered unhealthy for fish populations. Poplar and willow can take-up considerably more water compared to other crops historically used for land application of treated **effluent**. For example, TB54E Potential for a Hybrid Poplar Industry Using Recycled Water: An Environmental Application of Poplar in Idaho shows that alfalfa uses 14 inches of water per acre per season, whereas established stands of poplar may use up to 50 inches per acre per year, or more.

While these solutions require available land near the wastewater treatment facility for planting poplar or willow, they can often be implemented while maintaining existing farmland or open space rather than sacrificing lands to construct permanent facilities. Trees and shrubs have the added benefit of being a relatively low-tech and "green" solution for treating wastewater and stormwater runoff. These benefits can be multiplied by the numerous municipal treatment facilities within a region and provide the opportunity for biomass production to grow while aiding local communities (Figure 6). Proof of concept schemes in Northern Ireland (UK) and the Republic of Ireland are highlighted in TB58E Short-Rotation Coppice System: Environmental Applications from Northern and Republic of Ireland. These projects indicate that shrub willow is functioning well in managing wastewater treatment effluents from a variety of sources including agriculture, municipal, and industrial facilities (McCracken and Johnston 2015).

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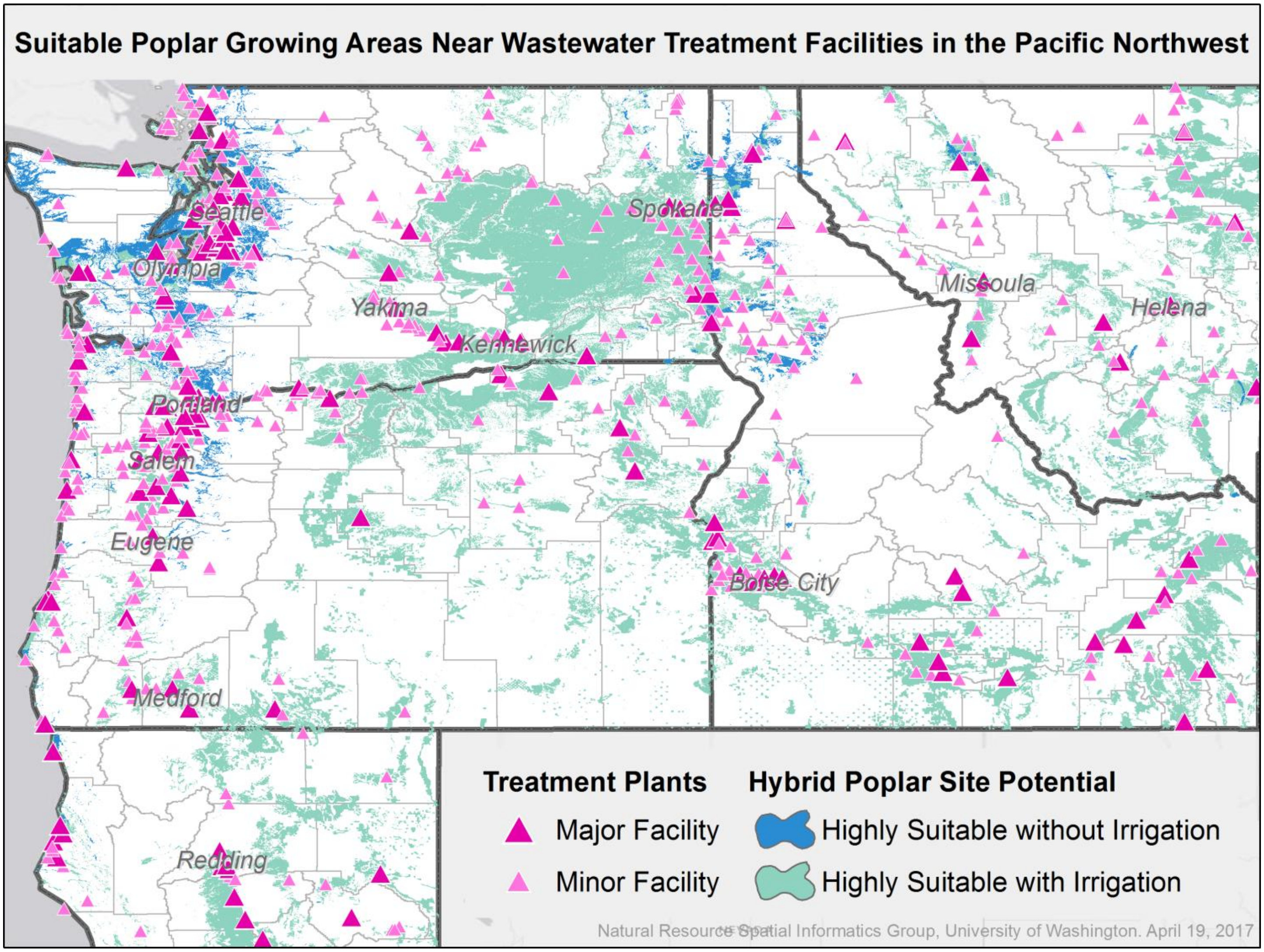

Figure 6. Lands that are suitable for growing poplar in the Pacific Northwest overlaid by locations of publicly owned wastewater treatment facilities (Rogers 2017; Rogers et al. 2014). The major facilities are designated by having design flows of greater than one million gallons of water per day based on EPA/State criteria.

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Poplars have proven to be an effective municipal wastewater management tool for biosolids as well. Treated biosolids are a beneficial recycled fertilizer product, which can be used on nearby farmlands to offset the need for commercial fertilizers. However, not all municipalities have ready access to suitable farming operations or are otherwise limited in available acreage and may need to dispose of biosolids in a landfill. This is an added cost and a loss of nutrients that could be recovered from the biosolids wastestream. The Metropolitan Wastewater Management Commission (MWMC), serving the municipalities of Eugene and Springfield, Oregon manages biosolids through land application at the facility's Biocycle Farm (TB53E Poplar for Wastewater and Biosolids Management: An Environmental Application of the Biocycle Farm). Here, the farm operators found that poplar's capacity for nutrient uptake is double that of a traditional land-application crop such as ryegrass, effectively halving the acreage needed or doubling the biosolids capacity of an existing operation. In areas where biosolids are not yet widely accepted by the public for local farm use, a non-food crop like poplar and willow can be a valuable asset to a wastewater treatment facility for biosolids disposal.

Stormwater and Snow Management

Poplar and willow farms can be used to intercept and filter stormwater runoff, preventing pollutants from entering waterways. Stormwater runoff is precipitation that falls on impervious surfaces, such as roads, driveways, and rooftops, and does not soak directly into the ground. Stormwater picks up contaminants such as heavy metals, organic compounds, nutrients, bacteria, and other pathogens as it runs across landscapes and roadways. Urbanization has increased the amount of runoff and is the primary cause of stream impairment and, in some cases, urban flooding. Poplar and willow's extensive root systems have an increased ability to capture, take up, and sequester or metabolize pollutants. These trees could be planted next to parking lots or otherwise be used to create buffer strips along roadways. Using poplar and willow for stormwater management applications is promising, but further research and development of this concept is necessary.

"Boutique Market" Opportunities

Poplar/willow growers may find that locally receptive niche (or "boutique") markets for their product opens doors and adds value compared to mass wood/fiber markets. Examples of boutique markets potential include:

1. Absorbents: bedding for livestock and poultry; erosion control socks.
2. Building materials: hollow door panels; architectural ceiling/wall panels; construction panels like cross laminated timber and concrete forms; plywood veneer.
3. Shipping materials: wine crates/boxes, pallets.
4. Charcoal products: briquettes; biochar soil amendments.
5. Board-sport cores: snowboards and wakeboards.
6. Craftwork: willow baskets and coffins, floral arrangements, and picture frames.
7. Fencing: posts, fence boards, and garden stakes.
8. Furniture: upholstery frames and cabinets.
9. Zoo browse: food for captive herbivores, like giraffe, moose, rhinoceros, tapirs, etc.

Snow also presents a weather-related challenge, impacting roadways in many cold-weather regions. Where large open fields are adjacent to roads, blowing and drifting snow can persist for days and weeks after a snow event. Living snow fences (LSF) that capture snow before it reaches roadways could be a viable solution (see TB57E Shrub Willows: An Ideal Plant Choice for Living Snow Fences with Multiple Benefits). A LSF is composed of rows of trees or shrubs, such as poplar or willow. These trees can be planted along roadways to capture snow as a low-cost alternative to plastic or wood fences that serve the same purpose. Moreover, LSFs could be harvested as biomass.

Biomass Applications, Benefits, and Opportunities

In addition to the direct environmental benefits, poplar and willow biomass can be sold for traditional wood products, bioproducts, and bioenergy. The vast majority of the poplar and willow biomass that is currently sold for traditional wood products and bioenergy comes from dedicated, large-scale tree farms. Growers with small-scale environmental plantings of poplar and willow may find established markets as well as local "boutique markets" for their biomass.

Bioproducts

The primary, current poplar market in the U.S. is in traditional wood products including veneers, non-structural forest products, and pulp fiber. In Oregon, early producers of cross laminated timber (CLT) panels are focused on using higher-strength species to ensure products exceed all engineering standards. Some innovators in the field see an opportunity in poplar's clean, bright appearance for finish-ready construction panels as well as its lightweight characteristics that can reduce the total building load. CLT that incorporates poplar as a component may need to be proven in the U.S. before it is seriously considered and widely accepted.[2]

In the near term, biomass from smaller-scale environmental poplar and willow plantings could be used to produce bio-based chemicals, such as lactic acid, methanol, and furfural. Some of these chemicals can be made into bioproducts such as paints, plastics, textiles, and chewing gum. The opportunity exists to develop bioproduct markets that depend on a reliable and consistent supply of biomass feedstocks from environmental plantings of poplar and willow.

Bioenergy

In the northeastern U.S., the current market for willow biomass is for generating electricity. In upstate New York, there are about 1,300 acres of willow being grown on private land. Most of the biomass is being harvested, integrated with forest residues, and used to generate **biopower** and heat. Poplar **hog fuel** has been used for electricity as well. There may be potential to expand into this area as coal-fired plants look to change the fuel that they are using for energy production.

In the future, as markets for biofuels develop, biomass from environmental applications could be incorporated into heat and power supply chains. Diversifying our resources away from fossil fuels is needed for national energy security and increasingly important as our climate continues to change. Transitioning to **renewable fuels** and products is absolutely critical, and biomass is a piece of that renewable puzzle. While biofuels such as corn ethanol have been used for some time, other plant sources such as switchgrass and pine have also been used. Poplar and willow are distinguished as woody perennial crops that can be managed as dedicated biomass plantations, in support of the bioeconomy.

Economic Benefits—Current and Potential

Utilizing poplar and willow biomass to build the bioeconomy has many positive aspects. However, economic viability is essential to its expansion and adoption. Economic benefits can also be thought of as ways to save money. The phytoremediation capability of poplar and willow can provide such a financial benefit to make the biomass revenues a secondary consideration. In fact, cost-savings for phytoremediation of wastewater relative to traditional technology offer a substantial benefit over cost (CH2M Hill 2010).

Ecosystem Services

Poplar and willow provide ecosystem services beyond land restoration, water treatment, etc. For more information on capturing and accounting for ecosystem services please see:

1. Chesapeake Bay (Woodbury et al. 2017)
2. Farms and Forests (Wainger and Ervin 2017)

[2] Market perceptions as noted by the Metropolitan Wastewater Management Commission's inquiry into potential Oregon markets for their poplar tree farm (per Todd Miller, City of Springfield).

The financial performance of poplar and willow environmental plantings could also benefit through Payments for Ecosystem Services (PES) in the form of tradeable carbon, thermal, or nutrient credits. Markets in these areas have grown rapidly since 1985 (Forest Trends Ecosystem Marketplace 2016). There may also be potential to bundle or stack the incentive programs so that multiple types of payments are captured for any one poplar or willow planting.

Assessments of scaling up willow production in New York for the production of renewable biofuels has indicated that between 45 and 59 jobs would be created for every 10,000 acres of willow biomass crops that are grown and converted to biofuels (Swenson 2010; Swenson et al. 2015). The majority of these jobs would be associated with crop production, harvesting, and transportation and are likely to occur in rural areas (Figure 7).

The biomass to bioproduct and bioenergy supply chain shows substantial potential for creating jobs and increasing energy security (U.S. Dept. of Energy 2016). Within current financial constraints due to low oil prices, this may not happen based on economic decisions alone. Using poplar and willow in value-added processing offered by **integrated biorefineries** can increase their economic viability. AHB research indicates that bio-based chemicals from poplar are cost competitive with those currently produced in petroleum refineries (Crawford et al. 2016). A biorefinery initially built to produce bio-based chemicals could scale-up over time to produce cellulosic ethanol and advanced biofuels from poplar and willow if these fuels become economically competitive with petroleum-based fuels.

“Transitioning to renewable fuels and products is absolutely critical, and biomass is a piece of that renewable puzzle.”

Figure 7. Mix of willow and forest residue chips for use at a renewable electricity facility in New York State.

II) BARRIERS TO SCALING UP POPLAR AND WILLOW BIOMASS

Barriers Overview

Despite the significant potential for use of poplar and willow for biomass and ecosystem services, many barriers impede their adoption. Current environmental plantings of poplar and willow provide an appreciable benefit, but they are widely dispersed among small-sized operations, making it difficult to aggregate sufficient biomass for commercial use. This roadmap is designed to address the logistical challenges and the lack of awareness and appreciation of poplar and willow's potential role in providing environmental services. There are significant challenges for introducing a "new" crop, including demonstrations of its use, grower acceptance, cost and availability of adapted varieties, as well as some social constraints. From the bioenergy point of view, there are challenges for markets and demand, as well as the feasibility of economies of scale. As a new bio-industry, there are challenges for creating an efficient and robust supply chain that will ensure the economic viability of proposed biorefineries. The biomass industry is not well-integrated with established industries. Petroleum prices, which are currently low, are also a barrier towards adoption of poplar and willow as bioenergy crops. Finally, for the industry as a whole, there are many risks and uncertainties that remain. For example, inconsistent policy support at the state and federal levels remains a significant hurdle. This section provides details on important potential barriers to the establishment of a biomass supply chain (Figure 8).

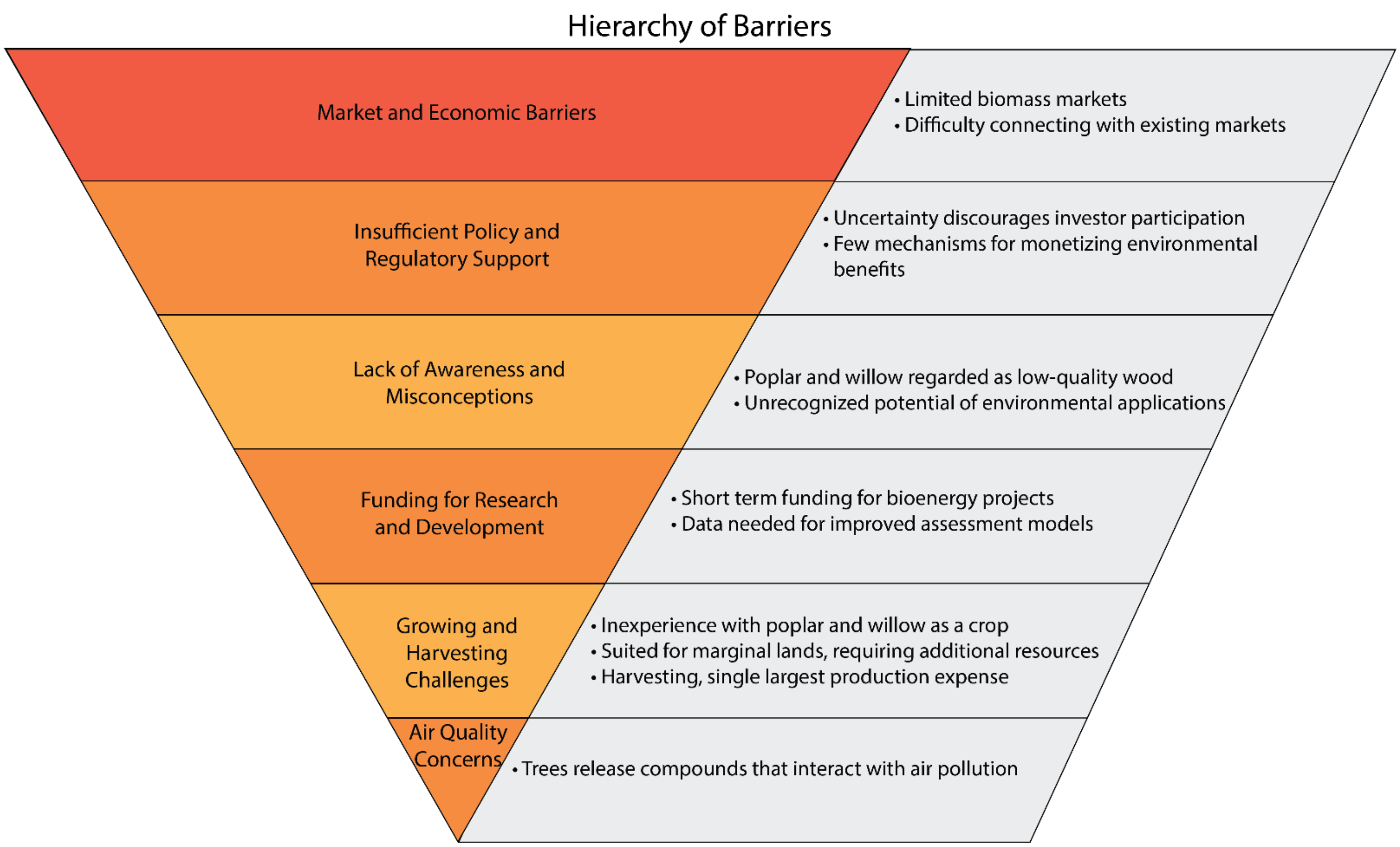

Figure 8. Hierarchy of barriers to scaling up the poplar and willow biomass supply chain.

Market and Economic Barriers

Market opportunities are limited for both poplar and willow biomass. In the Pacific Northwest, current buyers of poplar include producers of **kraft paper**, newsprint, veneer, charcoal, biomass electricity, compost, and mulch. However, numerous challenges exist in these markets. For example, from a strictly market income perspective and given current average prices for biomass (chips and hog fuel) produced from poplar, the economic return may be small (or even negative) after costs for tree establishment, maintenance, harvesting, and replanting. The MWMC Biocycle Farm in Eugene, Oregon (see TB53E Poplar for Wastewater and Biosolids Management: An Environmental Application of the Biocycle Farm) experienced increasing revenue from successive partial harvests over a three-year period, although not enough to recoup harvest expenses (Figure 9). To match the environmental and operational benefits provided by the Biocycle Farm, the MWMC is interested in pursuing a positive economic benefit as well. Their experience indicated three key needs to demonstrate net positive revenue from harvest: (1) growing larger-diameter trees through varietal selection at replanting and by optimizing irrigation and fertilization through their recycled water and biosolids application programs, (2) establishing ongoing market relationships for poplar—particularly saw logs and veneer, and (3) reducing costs of harvest and replanting by developing best management practices developed from experience.

Most growers are not likely to plant poplar or willow without either a reliable biomass market or substantial incentives. There needs to be rapid and dependable incentives to growing poplar or willow. Start-up costs for establishing poplar and willow farming operations can be high, although when using coppice management, establishment activities would not need to be repeated again for 20 to 25 years. Unless there are alternative benefits to growing poplar or willow—such as wastewater treatment or phytoremediation needs—there can be significant upfront investments for growers that must be carried for years before returns are realized from harvest revenues.

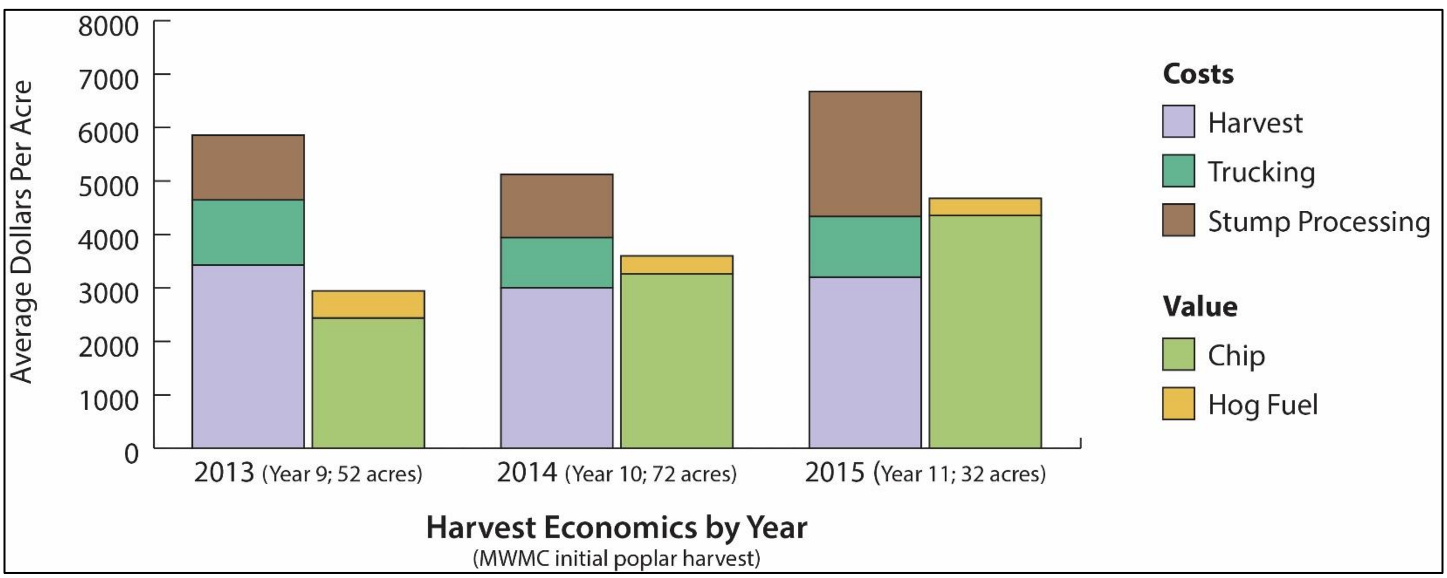

Figure 9. Per-acre cost comparison of three successive year harvests of the same planting of poplar trees. For each year, the left bar shows the total cost of harvest, trucking, and stump removal and the right bar shows the increasing recouped value of the harvested material over time. Data is from the MWMC's first trial of poplar harvest approaches from their Biocycle Farm (Eugene/Springfield, OR).

The current small acreages of poplar and willow are not of a sufficient scale to leverage markets for poplar and willow products. Even for markets currently feasible for poplar and willow, the small scale of operations makes it difficult to connect with those markets. The overall supply chain available for commercially produced poplar and willow is a small percentage of the total wood product market and the flow of product to market is not steady (due to limited harvest availability). Both of those factors make it difficult, or impossible, for biomass users to incorporate poplar and willow into their processes. At this small scale, economic efficiencies in processing, transportation, and marketing cannot be achieved. Establishing grower cooperatives, where growers can jointly negotiate with biomass buyers and coordinate harvesting activities, may help to alleviate some of these concerns.

For larger acreages, one of the challenges in developing poplar and willow systems is the need to develop not only the feedstock production system but also the market, harvesting, and logistical system at the same time. Developing all three parts of the system simultaneously can increase the risk associated with the system to a level that makes it challenging for landowners, companies, or end users to invest or commit to engage. This is especially true when the end user is a wood-based biorefinery, which has not yet been successfully demonstrated at commercial scale over extended periods of time.

Since the Great Recession and all-time-high oil prices in 2007 and 2008, changes in the world petroleum production have driven prices down below $60 per barrel from 2015 through the end of 2017. Since spring of 2018, prices have slowly increased to $79 per barrel and are projected to remain around $75 per barrel through 2019 (U.S. Energy Information Administration [EIA] 2018). AHB's studies indicate poplar biojet fuel becomes economically competitive with petroleum-based jet fuel when jet fuel prices reach $4.40 per gallon (Figure 10) (Bandaru et al. 2015). In contrast, jet fuel was priced just above $2.00 per gallon in 2015. Carbon taxes or subsidies may be required to enable bioenergy to be economically competitive with petroleum in the near term.

Compounding all of these issues is the consumer expectation for inexpensive fuels and products, which makes finding competitive alternatives difficult when the price of oil is low. There is limited current consumer demand for alternative fuels and products, with bioenergy making up a niche of the market. Biofuels, for example, comprise 5% of U.S. transportation fuels (as of 2014) and include ethanol, biodiesel, and renewable compressed natural gas. Many of the alternative-fuel vehicles in the U.S. can run on E85, which is a gasoline blend with 85% ethanol. However, many consumers may choose to purchase lower blends of ethanol because E85 is not common in gas stations. As of 2013, only 2% of all retail stations in the U.S. offered E85 (U.S. EIA 2014).

Figure 10. Biojet fuel from woody biomass was used in a 2016 demonstration flight. Photo courtesy of Alaskan Airlines.

Insufficient Policy and Regulatory Support

Clean energy and environmental policies, which could help relieve some market and economic barriers, are often slow to take root. On top of this, government officials, or other decision makers, such as federal and state environmental regulators, may not be fully aware of the environmental services provided by poplar and willow. While government programs have incentivized some production of bioenergy, the clean energy economy is far from mature and current energy platforms are slow in assimilating bioenergy.

The shifting political landscape, as well as instability in both federal (e.g., **Clean Power Plan**, **Renewable Fuel Standard** [RFS]) and state policies, create uncertainty for using poplar and willow for both environmental benefits and renewable fuels. Federal and state regulations do not address how poplar and willow can provide ecosystem services. At present, there are few mechanisms to monetize the environmental benefits that poplar and willow can provide in terms of clean water and soil, reduced erosion, and sequestered carbon. Like many issues of national scope, multiple agencies and departments have separate oversight of different issues and regulation of growing poplar and willow and biomass production. Policies that are favorable towards bioenergy are typically shorter-term promotions or tax breaks, so it is hard or risky for investors to commit to long-term investments based on these changing policies.

Policies regulating the next generation of bioenergy crops will likely also need to be evaluated. In the future, poplar and willow may benefit from the availability of **genetically engineered** (GE) varieties that could help in refining wood characteristics for specific problems and improve growth (Strauss et al. 2015). GE could also be used to contain non-native, hybrid tree species by engineering the DNA to make the plant sterile so the trees cannot reproduce. Currently, the commercial use of GE poplars needs approval from the USDA.

Lack of Awareness and Misconceptions

The benefits of poplar and willow are not generally well known, even within closely-related fields and industries. The key barrier is a lack of awareness concerning how poplar and willow can be used for environmental services (see the "Benefits" section). The application of poplar and willow for phytoremediation purposes is also undervalued.

Another barrier is the perception of poplar as poorer quality in the wood-products industry. When grown for longer rotations of eight years or more, poplar has shown desirable qualities for non-structural forest products. Poplar is a popular wood for finish material such as trim and moldings (Figure 11) (Carlson and Berger 1998). However, the wood may be perceived as weak and, therefore, mistakenly be seen as of low value in general.

Potential growers may either be unfamiliar with cultivating poplar and willow, or may have negative impressions. In the Pacific Northwest, some family farms diversified into growing poplar in the 1990s to bridge the uneconomical annual returns on marginal farmland and the multi-generational payback timeline on traditional timberland management. However, the decades-long changes and reductions in the timber- and fiber-products industry locally diminished the economic prospects of poplar.

Because of the lack of markets, some poplar farms were not properly maintained. Many farms were affected by wind, ice, and snow storms, which knocked down trees, making clean up difficult and dangerous. Over time, poplar farms were converted back to traditional farmland, often at considerable effort and expense, stigmatizing the crop. This experience underlines the importance of seeking advice from experts and current practitioners on available markets and the best varieties of poplar and willow for local conditions.

Figure 11. Poplar is used for many traditional wood products including finish grade lumber, trim, and molding.

Funding for Research and Development

Expanding opportunities for poplar and willow plantings and building a new bioeconomy will require long-term research and development, drawing on expertise from many disciplines and sustained social networks of committed visionaries. There are challenges in obtaining on-going funding and support for full project development. USDA NIFA, U.S. Department of Energy (DOE), and U.S. Environmental Protection Agency (EPA) have all provided various types of funding or support for poplar and willow to either investigate their potential for environmental applications or as a bioenergy feedstock. However, when funding on projects such as AHB, NEWBio, and IBSS terminates, it will be extremely difficult for their common goals of building a bio-based economy to be realized.

Funding for long-term research is necessary for poplar and willow grown as a short-rotation coppice. These production systems are expected to last for seven or more cutting cycles, over twenty years. Current research trials have only been established for two cutting cycles. Monitoring and measuring changes in biomass yields through multiple cutting cycles will provide researchers with a better understanding of yield responses that can be applied to yield, economic, and life-cycle analysis models (Volk et al. 2018). As the foundation of the bioeconomy, research and development projects can help stimulate markets, inform policy, address misconceptions, and respond to challenges in adopting bioenergy crops, such as poplar and willow.

Growing Challenges

There are significant challenges for those interested in growing poplar or willow, and getting into the business may be difficult. Growers could face a steep learning curve of trial and error in establishing initial poplar or willow crops that could dissuade them from continuing, or from even starting. Even if growers are familiar with growing trees or perennial crops, it is not likely to be the experience needed to adapt to poplar and willow farming. Longer-rotation perennial crops like poplar and willow can add uncertainty to management, markets, and economics for growers. Confidence in the crop might be lacking due to: (1) multi-year rotations of three to 15 years and (2) variability in the range of sites that could be planted, which requires the adoption of unique management practices in response to specific field conditions and market demand.

In most areas, poplar and willow will not be able to compete with traditional crops on high value, irrigated farmland, but using resources such as municipal wastewater might make biomass crops more economical. On marginal land, poorer soils will make the trees more susceptible to drought conditions and will likely require additional resources, increasing costs for the grower. In addition, the trees require two to three years before they become established enough to provide full environmental functioning and might only be effective at remediating the top nine to 12 feet of contaminated soil.

Growers' Resources

- Sustainable Production Practices of Short Rotation Woody Crops in the Southeastern United States: A Guidebook for Cottonwood and Hybrid Poplar
- Shrub Willow Biomass Producer's Handbook
- A Grower's Guide to Short-Rotation Hybrid Poplar as a Bioenergy Crop in the Pacific Northwest.

As a non-standard crop, local farm suppliers, nurseries, extension agents, and other agricultural resources may not have the awareness and expertise needed to supply and assist the grower. Three USDA NIFA grants—AHB, IBSS, and NEWBio—have established networks of trained extension agents and specialists in their respective regions. In addition, landowners have been engaged in growing these crops in some of these regions, which has helped to develop and deepen the understanding of woody crop management in these communities. There is a broad network of sites that have been developed over the years (Figure 3) that provide a solid foundation to develop more extensive environmental applications with willow and poplar. However, support is not available in all locations that are suitable for growing poplar and willow, so experienced growers or experts should be sought out when planning a new project.

One of the greatest challenges will be obtaining suitable planting material, particularly in certain locations. Unfortunately, growers may not be able to find suitable material available for planting that is resistant to diseases and insects that are prevalent in their area (Dickmann and Isebrands 1999). Specialized varieties of poplar may be especially difficult to obtain.[3] A grower may need varieties that are best suited for specific environmental applications or that produce low amounts of pollen and cotton in the spring. There will be challenges in finding planting stock when numerous smaller operations are trying to source stock at the same time. Special orders of less common varieties may add to the cost and timeline of the project. Although planting stock availability is a significant barrier, it also presents an opportunity as nursery operations can expand to provide planting material to new biomass markets.

Harvesting Biomass

The cost of harvesting poplar and willow is typically the largest single production expense. Techniques for harvesting poplar and willow grown at commercial scales have been developed, especially for longer-rotation poplar that is harvested using traditional logging equipment. Harvesting technologies for short-rotation coppice poplar and willow have been extensively researched through the efforts of New Holland in conjunction with NEWBio, AHB, and IBSS (Figure 12). The New Holland harvester cuts the woody material with a coppice header fitted to a traditional forage harvester. In addition to this single pass cut and chip system, several other types of balers, stem harvesters and cut and chip systems have been developed in Europe and Canada for woody crops (Ehlert and Pecenka 2013). While these pieces of equipment still need to be improved and optimized, there are a variety of options available for harvesting woody crops at different scales. Although navigating harvesting equipment in saturated fields during wet seasons is not unique to woody crops, environmental planting of poplar and willow may be especially difficult to access, particularly for riparian plantings. In addition, the cost of the harvester may not be feasible for smaller-scale growers to purchase. However, grower cooperatives, custom operators, or other cost-sharing schemes may be suitable solutions to reduce harvesting costs.

When poplar and willow are used for phytoremediation purposes, another potential barrier relates to the accumulation of compounds in the woody material. More research is required on the fate of accumulated pollutants in biomass, focusing on environmental, occupational, and industrial risks (Abhilash and Yunus 2011).

Figure 12. New Holland developed a coppice header for use on a traditional forage harvester. This equipment is used to harvest poplar and willow grown on two-, three-, or four-year rotations.

Heavy metals such as copper, lead, and zinc can concentrate in the plant’s roots and shoots, although plants will limit the amount of compounds they will take up. Since sites are often unique, it is wise to sample poplar and willow biomass grown on brownfields prior to use to determine if the concentrations in the wood are a potential concern. Depending on the chemicals and metals present, some contaminated biomass may need to be properly disposed of as hazardous waste in a landfill. Some metals taken up by poplar and willow could be

[3] The Eugene/Springfield Metropolitan Wastewater Management Commission (MWMC) opted to replant mostly with a time-honored poplar variety, OP 367, not only for its growing characteristics but also partly because it was expected to be widely available for their large order (38,000 cuttings). Even so, the MWMC only had two regional suppliers (in western Oregon and western Washington) respond to their solicitation for bids.

extracted from the biomass through incineration and recycled. Other biomass would be suitable for renewable fuel production or other bioproducts (Pajević et al. 2016). More research is needed in this area to ensure that human health is protected and conversion efficiencies are maintained (Abhilash and Yunus 2011).

Air Quality Concerns

Unlike traditional agricultural crops, many emerging bioenergy crops, such as poplar, emit significant quantities of **volatile organic compounds** (VOCs) (Rosenstiel 2016). These organic compounds may cause health concerns and influence public perception of poplar and willow farms. In the presence of sunlight, VOCs will combine with nitrogen oxides (NO_X), a common air pollutant that comes from vehicles and industrial facilities, to form ozone. While ozone is beneficial in Earth's atmosphere, at ground level it is an air pollutant that is harmful to breathe and is the main ingredient in urban smog. Because of the potential impacts to air quality, a poplar farm's location, scale, and choice of tree variety should be carefully considered to limit impacts to urban air pollution (Figure 13) (Rosenstiel 2016).

"Even if growers are familiar with growing trees or perennial crops, it is not likely to be the experience needed to adapt to poplar and willow farming."

Figure 13. Researchers assessed the release of VOCs by hybrid poplar varieties at the AHB demonstration site in Jefferson, OR. The contrasting greens of poplar trees indicate different varieties which researchers found to emit different levels of VOCs (Rosenstiel 2016).

III) SOLUTIONS FOR THE ROAD AHEAD

Solutions Overview

A primary goal of the 2016 National Working Forum was to find solutions to overcome the challenges of growing poplar and willow for environmental benefits and as a biomass feedstock for biofuels and other industries. Integrating biofuel crops into the agricultural landscape can produce diversified cropping systems that could deliver multiple ecosystem services and resiliency to environmental stresses (Robertson et al. 2017). During the Forum, we identified areas of development for potential solutions including market viability, policy support, and consumer awareness and demand (Figure 14). A focus on monetizing environmental benefits through ecosystem service markets and developing robust stable biomass markets are key to successful deployment. There are opportunities for better integration with woody biomass sourced from managed forests. Feasibility can be increased through better political, policy, regulatory, and financial support, especially over the long term. Finally, consumers can play a role by learning about and demanding renewable products and services that poplar and willow can provide.

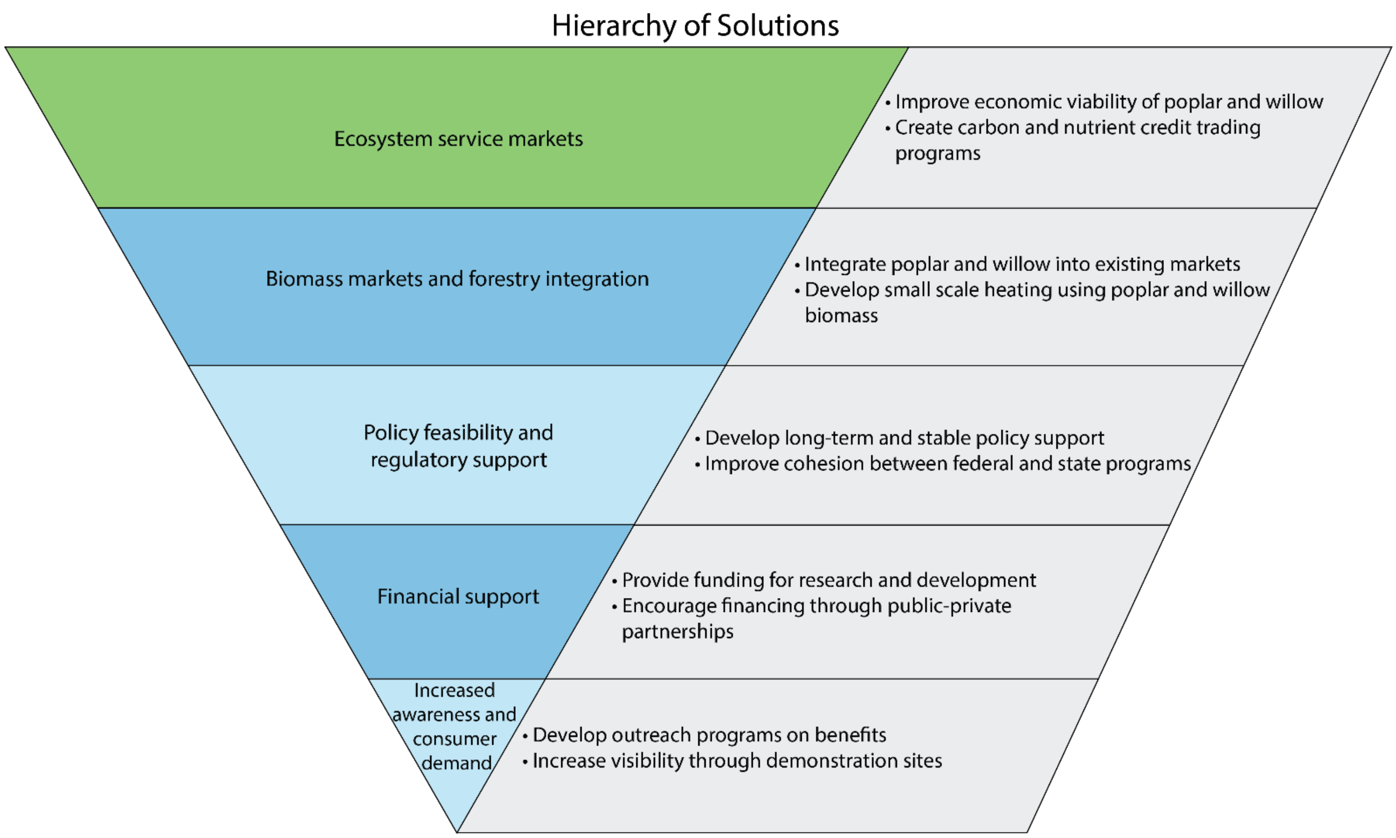

Figure 14. Hierarchy of solutions to scaling up a poplar and willow biomass supply chain.

Ecosystem Service Markets

For poplar and willow environmental plantings to become more common, they need to become economically viable, especially in the long term. Land managers and others growing poplar and willow for their environmental benefits will need to understand the wide range of costs and benefits in growing these trees. Once this is known for the given system, managers may be able to monetize benefits by obtaining tradeable market credits or payments for ecosystem services (PES) that are a match with the benefits that poplar or willow can provide.

Carbon and nutrient credit trading programs seem the most feasible for monetization in the near term. Examples of Nutrient Credit Trading programs exist in Pennsylvania, Maryland, and Virginia. These programs focus on reducing nitrogen in waterways, and trades usually occur between point-source polluters, such as wastewater treatment plants, and non-point source polluters, such as farmers. At present, growing poplar or willow for wastewater management is one of the most widespread environmental planting applications and is low cost compared to the millions of dollars that many municipalities and small communities spend in wastewater treatment (Oregon DEQ and Oregon ACWA 2014). Organizations, such as the National Network on Water Quality Trading, seek to create a national dialogue on how water quality trading can contribute to clean water goals. Water quality trading can offer a flexible, potentially cost-effective approach to reducing pollution and controlling temperature in waterways. Under such a system, point-source polluters can work with landowners within a watershed to implement conservation and restoration projects that improve water quality (Willamette Partnership; Freshwater Trust). Similar credit-trading programs focusing on sediment and phosphorus could be beneficial as well. Since poplar and willow readily take up nutrients from the water, programs such as these could be incorporated into the business model of a bioenergy farm.

Carbon markets are also an option and may support larger scale plantings of poplar or willow. In the Mississippi Alluvial Valley, GreenTrees is reforesting thousands of acres of marginal farmland with poplar trees and generating American Carbon Registry credits. The biomass from this reforestation in Mississippi may also be sold to emerging industries in the bioeconomy. In the western U.S., state-enacted low-carbon fuel policies are in place that create a market for carbon credit trading (see the “Policy Feasibility and Regulatory Support” section for more information).

It seems that bundling the incentives created through ecosystem service markets related to water quality, carbon, and others could help to increase the economic viability of making bioenergy and bioproducts from poplar and willow. Poplar and willow systems could be designed so that multiple environmental benefits are gained. This approach could improve the financial feasibility of poplar and willow systems while addressing many environmental problems.

Biomass Markets and Forestry Integration

One way to build an industry is to make use of existing markets for woody biomass, such as heating and power, to develop feedstock production and logistics systems. Poplar and willow coppice systems are more aligned with the agricultural sector than the forestry sector in terms of politics, regulations, and harvesting methodology. However, timberlands and poplar and willow farming both produce woody biomass that can be used for bioenergy, and these feedstock sources should be integrated. Most of the characteristics of poplar and willow biomass such as ash, moisture, and energy content are similar to forest residues (Eisenbies et al. 2015). Integrating the biomass with forest residues can provide a market for landowners growing this material, and the USDA Biomass Crop Assistance Program (BCAP) provided some incentives to reduce the risk of establishment and early growth for landowners. Incorporation does happen in Alberta, Canada where poplar tree farms are combined with timber resources to produce pulp products (Alberta Pacific).

For smaller poplar and willow plantings focused on environmental applications working with forestry may be an effective approach. There may be potential to develop small scale heating or **Combined Heat and Power** (CHP) systems to make use of the poplar and willow biomass in combination with other woody biomass. Small wastewater treatment systems are distributed across many rural areas, and these communities often are potential locations for developing woody biomass heating systems. The material can be grown locally and used locally to address a number of different issues and generate benefits for the community.

A variety of stable markets for poplar and willow biomass will help both with increasing environmental applications and developing a bioenergy and bioproducts industry. The challenge is to identify the economic bridge for near-term expansion of poplar, willow, and markets in order to prepare for advanced biofuels and bioproducts. Once small supply chains exist that integrate biomass from environmental plantings of poplar and willow, it will be more feasible to expand to larger industries, such as the biofuel industry. Stability in traditional wood product markets, as well as pulp and paper markets, can help form a bridge to new bio-based chemical and biofuel markets (Figure 15). Promoting specialty products made from poplar or willow (see "Boutique Market Opportunities") could also help.

Markets may be regional or national in scope and be driven by carbon-reduction goals, biofuel mandates, or commercial biofuel investment. In the near term, poplar and willow biomass industries may be made more feasible by making use of traditional wood products or heat and power markets. Once small supply chains exist that integrate biomass from environmental plantings of poplar and willow, it will be more feasible to replicate these across the landscape and then expand to larger industries, such as the biofuel industry.

Policy Feasibility and Regulatory Support

Awareness among policymakers and regulators needs to increase to clear hurdles and open the path forward to develop poplar and willow bioenergy systems. Long term and stable policy support is critical to the development of bio-based markets and the bioeconomy. Cser and Boby (2015) describe how state, federal, and international policies significantly influence the development of the biofuels industry through tax incentives, subsidies, federal or state renewable fuel standards, and energy mandates.

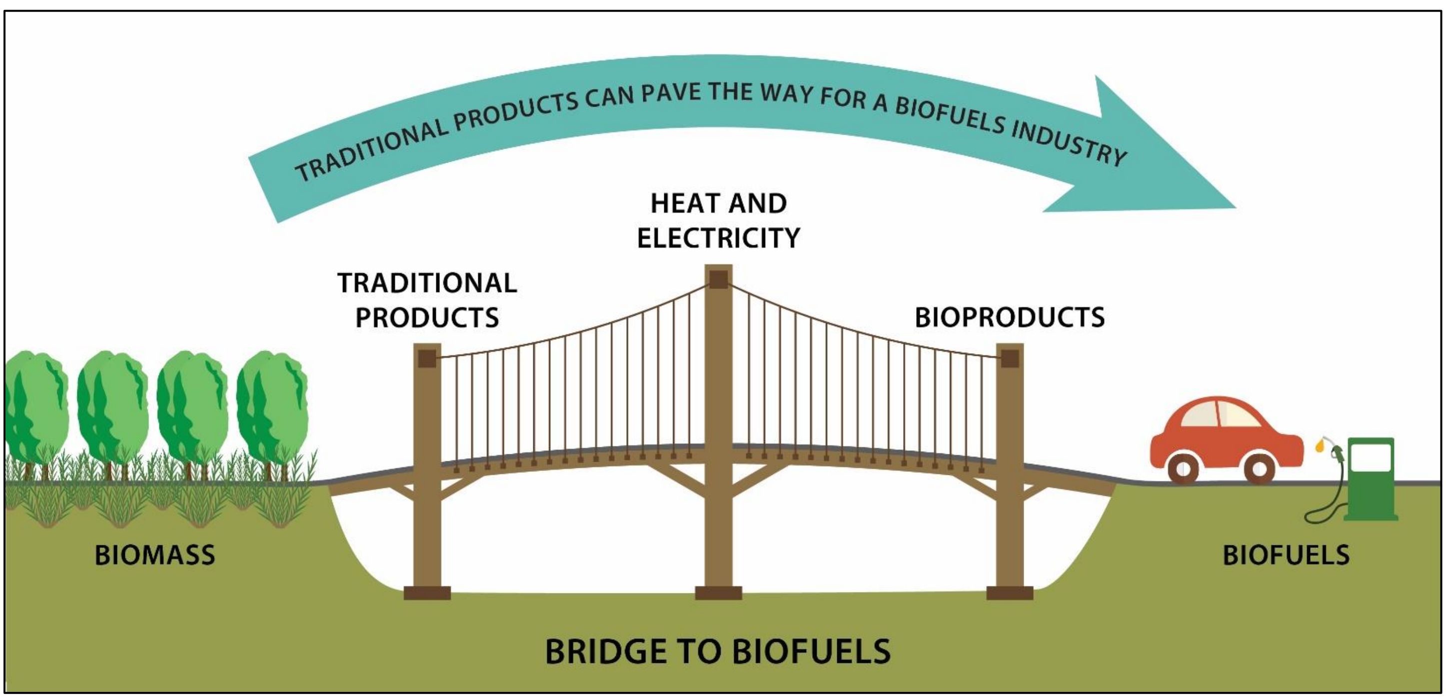

Figure 15. Having a strong industry of traditional products from poplar and willow can help build an industry of bio-based chemicals from poplar and willow, which could be a foundation for a future biofuel industry.

When funded, the USDA Biomass Crop Assistance Program (BCAP) provides financial incentives for growing poplar or willow if the biomass could be utilized by a qualified facility. The program was not funded in 2018 and future funding is uncertain. Having a program like this in place may be vital for a successful poplar and willow biomass industry and biorefineries.

Another policy that can provide support for poplar- and willow-based liquid fuels is the Renewable Fuel Standard (RFS). The RFS was created under the Energy Policy Act of 2005, and expanded to its current form (RFS2) through the Energy Independence and Security Act of 2007 (EISA 2007). The RFS establishes annual mandates for different types of biofuels. In the EISA, Congress set a volume schedule through 2022 (Figure 16), though the U.S. EPA has the authority to adjust these volumes based on a number of criteria. The RFS policy does not include any mention of potential environmental benefits offered by biomass feedstocks.

Life Cycle Assessment

For poplar or willow biofuels to be applied to the RFS or other programs, the **carbon intensity**, or how much carbon is emitted relative to the intensity of the process, should be measured using a life cycle assessment (LCA).

Recent LCAs of willow biomass crops show that they have the ability to sequester carbon while producing a renewable source of biomass and have a high **net energy ratio** (Caputo et al. 2014).

EPA's initial assessment of poplar and willow feedstocks showed that they successfully reached the greenhouse gas reduction goals specified in the RFS.

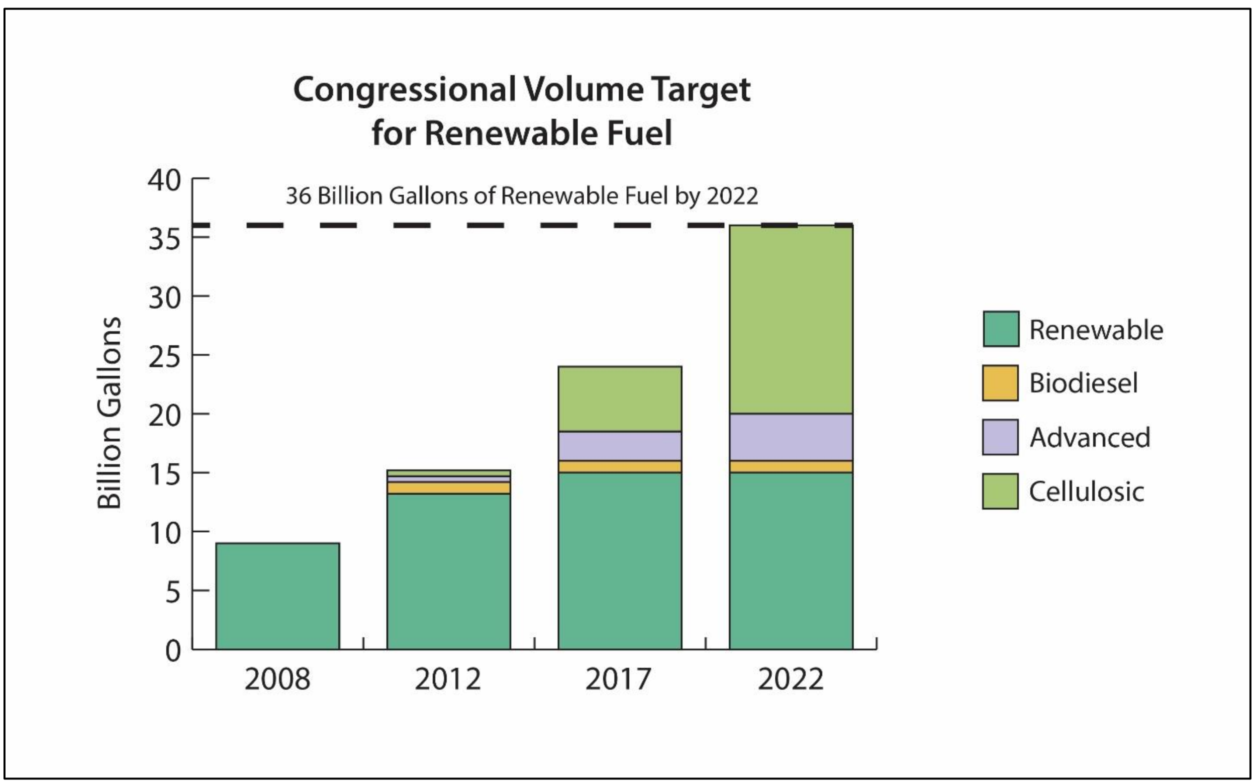

Figure 16. The RFS mandates that 36 billion gallons of renewable fuel be blended into domestic transportation fuels by 2022. (Adopted from EISA 2007.)

The largest growing fuel category is for **cellulosic biofuels**, which are scheduled to reach 16 billion gallons in 2022 under the statute. These are fuels whose feedstock is comprised primarily of cellulosic material and meet a 60% lifecycle greenhouse gas reduction threshold against the petroleum alternative as determined by the EPA. As part of the AHB research, an LCA was done to determine the greenhouse gas reductions that poplar biofuels could obtain (Figure 17).

In November of 2016, the EPA issued a proposed determination for select varieties of poplar and willow to be included as credit-generating cellulosic feedstocks under the program. If the EPA finalizes this determination, production of each gallon of poplar- and willow-based biofuel can also generate a cellulosic (D3) **Renewable Identification Number** (RIN), which are the key credit and compliance mechanism under the RFS and offer the potential to make cellulosic biofuels more economically attractive to renewable fuel producers.

Work will need to be done to create policies that support the increased sustainability of growing bioenergy crops for environmental benefits compared to other energy sources. Policymakers can play a key role in supporting a bioeconomy and environmental services from poplar and willow plantings, balanced with clear and sensible regulatory compliance methods.

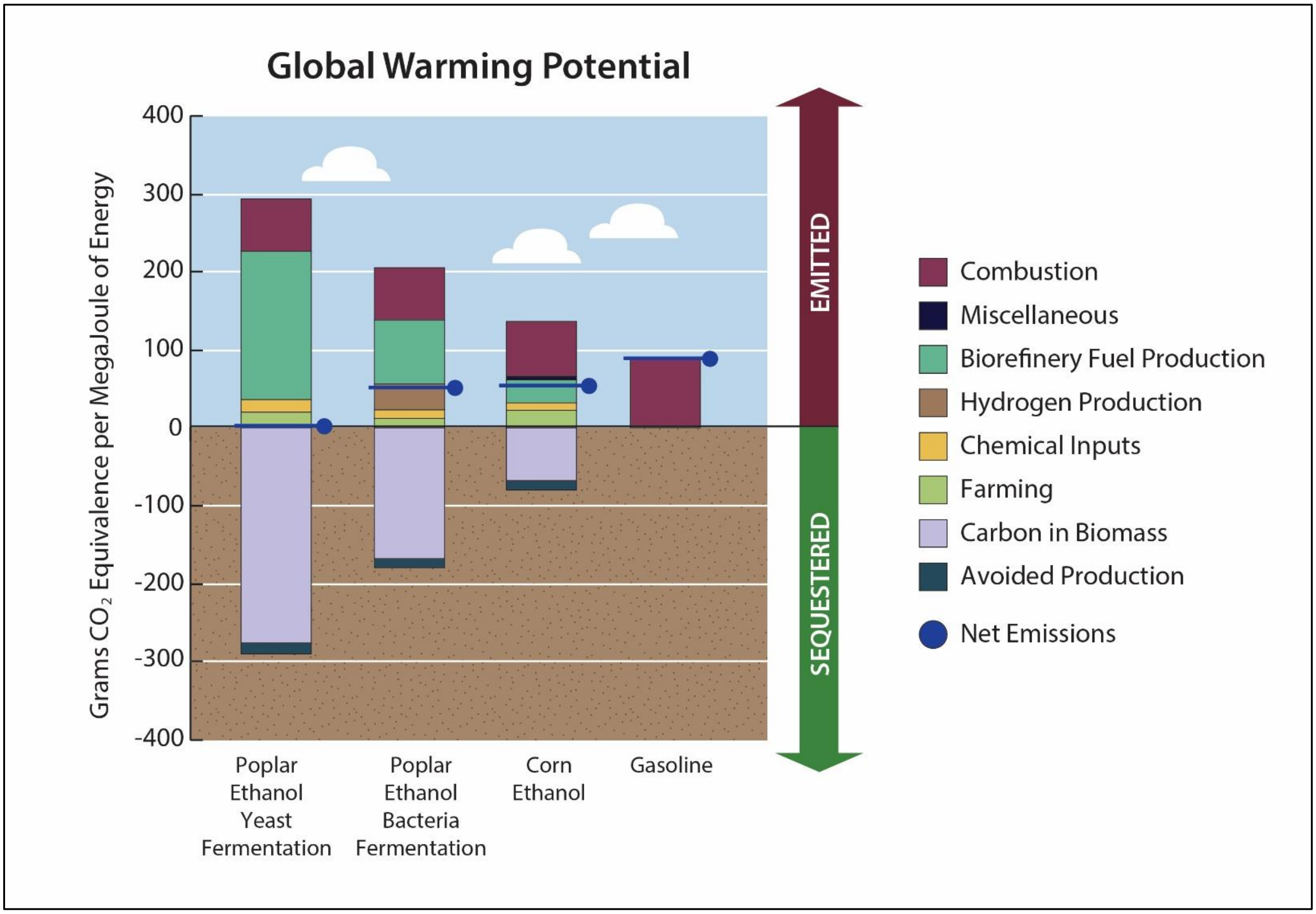

Figure 17. Life Cycle Assessment (LCA) research conducted through AHB estimates that poplar-based ethanol, using either yeast or bacterial fermentation pathways, have a Global Warming Potential (GWP) that is 97% and 50% lower than the GWP of gasoline, respectively (Budsberg et al. 2015). When compared per unit of land the two pathways achieve similar reductions because almost all the carbon in the biomass is used during bacterial fermentation processes (yeast fermentation loses up to one third of the carbon as CO_2).

Currently, the general lack of awareness about poplar and willow and alternative bioenergy hinders the clarity and commitment needed from policymakers—whether they are elected officials or agency leads. While a given policymaker may, on paper, seem to be aligned with the goals and objectives of poplar and willow bioenergy, the environmental, social, and economic benefits might not be clear, and opportunities could be lost without ensuring those connections are made. Values which may resonate with policymakers include:

- Economic growth/industrial development, especially in rural communities
- Energy independence/security
- Climate change mitigation
- Agriculture/forestry sector opportunity
- Tax-based increases and retaining dollars in local economies
- Sustainability and resilience

Applicable policies do exist in some states, and seeking state support may be the best road forward. For example, Oregon and California, along with the Canadian province of British Columbia, have adopted low-carbon fuel programs. Through these programs, California and Oregon have implemented credit-trading programs to reduce the carbon intensity of the transportation fuels in use in those states.

More states may follow in their footsteps, especially if federal programs and support are lacking. Using this market-based approach, renewable-fuel producers sell credits creating additional returns on the fuels they produce, and traditional refineries and fuel importers purchase credits to meet their low-carbon fuel obligations. Critics of these programs state that the price of the credits will be passed on to fuel consumers.

Ideally, the federal funding agencies should be working together to support programs to improve environmental quality and build the bioeconomy, especially when there are crossover interests among multiple agencies. This will streamline the regulatory process and eliminate conflicting messages. The first step may be to identify which existing agency programs can be supportive, such as the Biomass Research and Development Initiative (BRDI), which is a joint effort of USDA NIFA and the U.S. DOE. Given the national importance of developing and implementing a bioenergy-ready infrastructure, federal programs need to continue to support this work financially, technically, politically, and socially.

Along with stable policies and program support to promote a path toward a poplar and willow bioenergy future, regulatory challenges need to be addressed to remove current hurdles blocking adoption. This support would be most effective at both the state and federal levels, however, it may be most likely to occur in terms of state-level regulations, such as state low-carbon fuel standards. As part of this, different coalitions, such as state clean air and water agencies, may be able to provide support in getting necessary regulations in place. The desired regulatory system would place both economic and environmental value on growing poplar and willow to provide ecosystem services.

Financial Support

Additional necessary support will need to occur in terms of funding. Federal funds will be needed to develop some initial projects on growing poplar and willow for environmental benefits and to provide feedstock for the bioeconomy. This has started to happen with recent grant opportunities from USDA NIFA and others (Goldner 2015). More funding support along these lines will be needed to jumpstart the poplar and willow bioeconomy and the integration of environmental benefits. We envision bringing together different funding agencies to see multiple benefits across agencies and across projects.

For commercialization, it may take a combination of public-private sector investments to financially commit to poplar and willow bioenergy developments. Financial support of this nature could reduce the risk and make growing poplar and willow acceptable to many potential growers, including municipal organizations. Public-private partnerships have emerged to some degree, especially within projects such as AHB, IBSS, and NEWBio. However, these partnerships would be much more successful with more stable policies that focused on long-term solutions, thus, incentivizing investment.

Increased Awareness and Consumer Demand

Many potential growers, biochemical engineers, regulators, policymakers, and the general public are not aware of the potential for poplar and willow to remediate environmental problems and provide biomass to produce products that society uses on a daily basis. The multitude of benefits, both direct and indirect, that poplar and willow can provide could address social needs and goals. To increase awareness, a fully developed outreach program will be paramount to create awareness on the current and potential benefits of growing poplar and willow. To create an outreach program focused on the benefits of these trees, it will be most effective to align organizations with common and overlapping interests such as university Extension offices, conservation districts, environmental NGOs, and municipal and industrial wastewater facilities. These groups and others can work together as a coalition to increase awareness. Flagship projects tailored to the environmental issues specific to a region may be helpful (Figure 18). In reaching out to various agencies and industries, it may be beneficial to find a "champion" within the organization to align with the core goals of growing poplar and willow.

One way to increase visibility and awareness is through regional demonstration sites that showcase the environmental application of poplar or willow, while growing a bioenergy feedstock. In Ireland and Northern Ireland, willow is being grown as an economical, environmentally-sound, and sustainable alternative to building more expensive wastewater treatment facilities (See TB58E Short-Rotation Coppice System: Environmental Applications from Northern and Republic of Ireland).

In the end, societies and consumers will need to demand environmental services, products, and fuels that offer more sustainable solutions for common needs and wants. There is a potential to produce a broad and diverse array of products from poplar and willow that begin to replace petroleum. However, for many consumers, the perception of current use of these trees versus the potential solutions they offer the environment is disconnected. Marketing will be needed to identify products that are produced from locally and sustainably grown biomass. These efforts will need to extend to the corporate, commercial, industrial, and international markets.

There is a slow but steady shifting of public opinion toward bioenergy. However, individual cost remains the number one consumer choice factor. There may be other factors and consumer education may be critical for large scale adoption (Salvo and Huse 2013). Public opinion is also impacted by criticisms of past bioenergy programs, including the current leading ethanol feedstock, corn. A clear accounting of costs and benefits are needed to gain critical mass in public opinion.

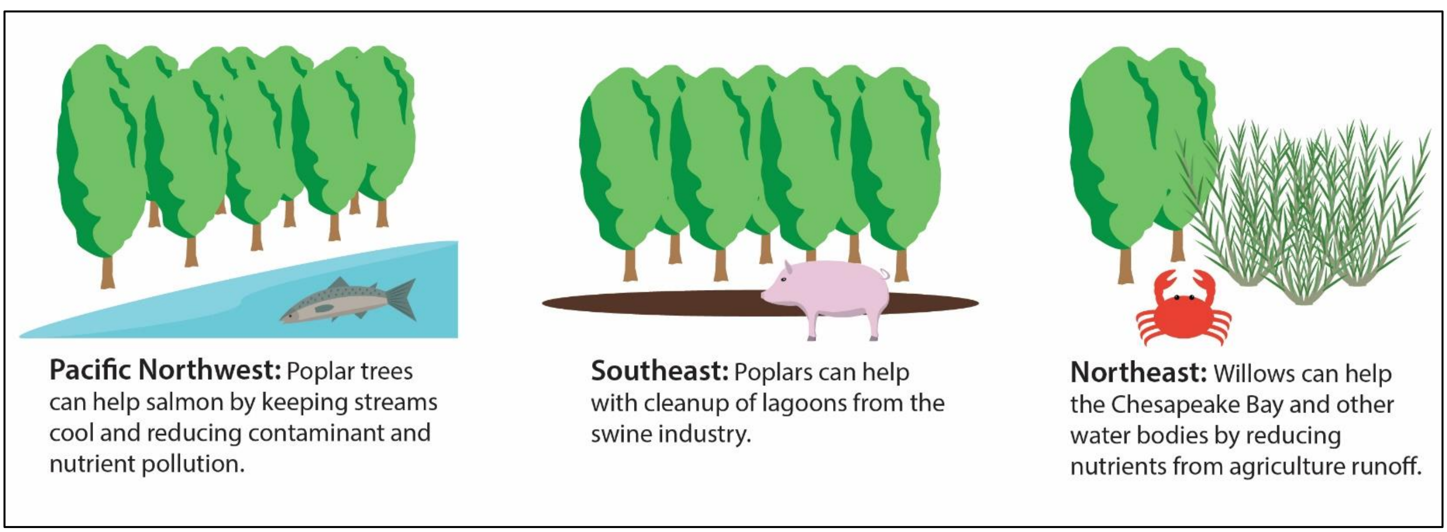

Figure 18. Poplar and willow trees can be used to focus on regional environmental problems.

Roadmap Conclusions

Poplar and willow are short-rotation woody crops that can provide biomass for the bioeconomy, wood for the forest-products industry, and associated benefits for societies and the environment. This concept has been successfully demonstrated in several countries around the world, and to some extent in the U.S. Opportunities to apply the existing knowledge base and expand the use of poplar and willow for environmental benefits and biomass production are now emerging in the U.S. These opportunities, as well as potential barriers, were highlighted and explored at a National Working Forum held in Portland, OR in 2016, and key concepts and strategies for implementation identified at the Forum have been included in this roadmap.

Poplar and willow can provide a wide array of positive environmental benefits including more tree cover, ecological restoration, and mitigating both point and non-point source pollutants. Many of these environmental benefits can have overlapping positive impacts in terms of protecting human health and providing other social and economic benefits to communities, such as natural aesthetics, job creation, and saving money by putting waste and effluent to a beneficial use. Numerous renewable products, such as biodegradable plastics and high-value bio-based chemicals, can be generated as coproducts from the processing of poplar and willow biomass. Bioenergy crops like poplar and willow differ from other forms of renewable energy in that they are living systems that often improve ecological health in terms of soil, wildlife, and carbon sequestration.

While many of these benefits are a positive consequence of the trees' primary use, some multifunctional poplar and willow systems, such as riparian buffers and wastewater treatment plantings, can improve the economics of the system. These multifunctional uses can lower the break-even price of biomass and shorten the payback time for the grower. Still, a lack of market opportunities and economic incentives make obtaining investors difficult and creates barriers to implementation and scale-up of poplar and willow systems. Multiple harvest rotations of three years or longer are required to break even and achieve a profit. This timescale also adds risk to the investor and grower if there is uncertainty about future biomass markets. Market uncertainty is related to shifting state and national policy on renewable energy, especially bioenergy.

Despite these barriers, there are some promising pathways to developing poplar and willow systems that provide economic, environmental, and social benefits. Developing awareness of these systems amongst potential growers, industry, government, and NGOs will continue to move poplar and willow away from a niche practice toward broader acceptance and implementation. To provide better information on the range of benefits that poplar and willow provide, we recommend continued research to strengthen the case for investment, favorable policy, and system scale-up. The Environmental Applications Series provides several examples of successful implementation of these systems and highlights the potential for replicating them across the U.S. landscape. There are thousands of sites and millions of acres across the U.S. that could benefit from poplar and willow systems as a productive use of marginal land, reclamation of former industrial sites, wastewater treatment, and other applications. Thus, there is much opportunity to expand the use of poplar and willow for a variety of purposes that provide a homegrown renewable source for energy and everyday products, as well as numerous additional benefits to people and the environment.

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Glossary

bio-based chemicals—Chemicals derived from biomass feedstocks that can replace petroleum-derived chemicals. Bio-based chemicals can be used to manufacture a wide range of products such as bio-based plastics, lubricants, paints, cosmetics, pharmaceuticals, and other bioproducts.

bioeconomy—Refers to the parts of the economy that uses renewable biological resources, such as crops, forests, animals, fungi, and micro-organisms, to produce food, materials, and energy.

bioenergy—Energy derived from the conversion of biomass that is burned directly or processed into liquid and gas fuel.

bioengineering—The application of engineering principals to biological systems.

biomass—Literally the mass (weight or volume) of biologic material (typically plant, but can include animal source or animal waste) of a unit (such as an acre or a single tree). In this document, "biomass" mostly refers to the woody material produced from poplar and willow. Often "biomass" is a term used in the energy industry to refer to energy, or energy value, derived from plants and trees.

biopower—Using biomass to generate electricity through direct burning or conversion to fuel.

bioproducts—Products made with material derived from biomass.

biosolids—A beneficial, nutrient-rich resource made mostly of organic matter including plant, animal and human waste, water, and microorganisms produced from the treatment of wastewater.

brownfields—A term used to describe land previously used for industrial or commercial purposes that may have pollution, including soil contamination, due to hazardous waste.

carbon intensity—Quantifies carbon in a product or fuel's life cycle and compares them to traditional petroleum based products and fuels.

cellulosic biofuels—Renewable fuels made from inedible plant material including poplar and willow as well as crop residues like corn stover and wheat straw, wood residues, and other waste products. Cellulosic biofuels include cellulosic ethanol as well as other fuel products. Under the Renewable Fuel Standard, cellulosic biofuels must be produced from cellulose, hemicellulose, or lignin and must meet a 60% lifecycle greenhouse gas reduction from the petroleum alternative as evaluated by the EPA.

Clean Power Plan—An Obama administration policy aimed at reducing carbon pollution from power plants and encouraging cleaner and lower-polluting U.S. energy.

combined heat and power (CHP)—Also known as cogeneration, CHP is the concurrent production of electricity and thermal energy that is located at, or near, the point of consumption.

contaminants of concern (COC)—Broadly defined as any synthetic or naturally occurring chemical or microorganism, including nutrients, pharmaceuticals, industrial wastes, pathogens, and heavy metals. These contaminants are not commonly monitored in the environment but have the potential to enter the environment and cause known or suspected adverse ecological and/or human health effects.

coppice—A silvicultural method in which trees and woody plants are cut near the base of the plant, stimulating new growth from the plant base that regenerates the stand.

ecosystem services—The life-sustaining benefits we receive from nature—clean air and water, fertile soil, pollination, flood control, and other benefits that are important for human and ecological health and well-being.

effluent—Treated wastewater that flows out of a treatment plant, sewer, or industrial outfall.

feedstock—Biomass used to produce bioenergy, either in its original form or converted to fuel, and bioproducts.

genetically engineered (GE)—Also called genetic modification or GMOs, the process of manually altering an organism's DNA to modify the characteristics of that organism. Examples include modifications to make plants sterile, increase pest resistance, and to enable plant tolerant herbicides.

geomembrane cap—A cover that is placed over contaminated material, such as a landfill or contaminated soil. The caps are used to avoid the spread of contaminates offsite into groundwater, lakes, and streams.

hog fuel—Ground up wood waste that can include bark and twigs as well as wood chips. Hog fuel has value as boiler fuel, charcoal, coarse paper products, particle board, mulch, and other applications.

integrated biorefinery—A biorefinery that uses a broad range of feedstocks and conversion technologies to efficiently convert biomass into commercially viable biofuels, biopower, and other bioproducts.

kraft paper—Also referred to as "sack paper," kraft paper is a strong, durable, low-lignin, dark-colored paper designed for packaging materials, such as paper grocery bags.

land reclamation—The use of lands that have been degraded by human activities or impaired by natural phenomena.

marginal lands—Typically characterized by low potential for productive agricultural operations and reduced economic returns or by severe limitations for agricultural use.

net energy ratio—Comparison of the amount of useable energy produced from an energy resource to the amount of energy used to create that energy resource.

phytoremediation—The direct use of plants to remove, transfer, stabilize, and/or destroy contaminates in soil and ground water.

recycled water—Processed wastewater that is used for other purposes, such as irrigation or replenishing surface water, also called reclaimed water.

renewable energy—Energy that is generated from resources that are naturally replenished on a human timescale. Renewable energy can come from sunlight, water, ocean processes, and geothermal heat, as well as biomass.

renewable fuels—Fuels produced from renewable resources including biomass.

Renewable Fuel Standard—A federal program, administered by the U.S. Environmental Protection Agency (EPA), that was authorized under the Energy Policy Act of 2005 and expanded upon under the Energy Independence and Security Act of 2007. The policy requires transportation fuels sold in the United States to contain a minimum volume of renewable fuels.

Renewable Identification Number (RIN)—A serial number assigned to a batch of biofuel for the purpose of tracking its production, use, and trading as required by the EPA in accordance with the Renewable Fuel Standard.

short-rotation woody crop—Fast-growing tree or shrub species that are harvested after growing periods of up to 15 years such as poplar, willow, and eucalyptus.

total maximum daily load (TMDL)—A regulatory term in the U.S. Clean Water Act that identifies the maximum amount of a specific pollutant that can be discharged into a water body while ensuring that the water body attains water-quality standards.

urban blight—The deterioration of an area in a town or city whereby previously functioning infrastructure falls into disrepair and decrepitude.

viewshed—A landscape vista that is visible from a certain vantage point.

volatile organic compounds (VOCs)—Gases emitted from certain solids and liquids. The compounds are volatile because they easily evaporate into the air at room temperature. Most smells and odors are VOCs, while some VOCs have no noticeable smell. VOCs can affect air quality and, at high concentrations, some VOCs can be toxic.

wastewater—The drain waste from the sanitary sewer and septic facilities of a community that is collected for regional treatment to clean and restore. The water portion of the waste to the water cycle can be reused or returned to the water cycle. Other terms may include "sewage" or "influent" (the untreated wastewater at the front end of the treatment process), and "effluent" (the treated water after completion of the treatment process).

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