USDA Biomass Crop Assistance Program

Project Area 10 - Northern New York Willow

Annual Report 2014





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1. Crop Area Status

There are currently 1187 acres of willow biomass crops enrolled in USDA BCAP project area 10 in northern New York State (Figure 1, Table 1). Of these 1187 acres, 836 acres were planted in 2013, and an additional 351 acres of previously established crops (planted 2008 and prior) were also enrolled in the program. A small portion (8.3%) of the newly planted acreage is targeted to be replanted in 2015 based on evaluations conducted in 2013 and 2014, and the response from USDA for funding assistance. Mature crops on 130 previously established acres were harvested in 2013. In 2014, about 40 acres of mature crops were harvested across two sites. The staggered harvesting of maturing crops, along with the normal variation in growth rates among new crops, is creating the opportunity to harvest substantial acreages of willow biomass from various locations on an annual basis going forward, providing a consistent supply of willow to compliment other biomass feedstocks at two ReEnergy biopower facilities in the region.

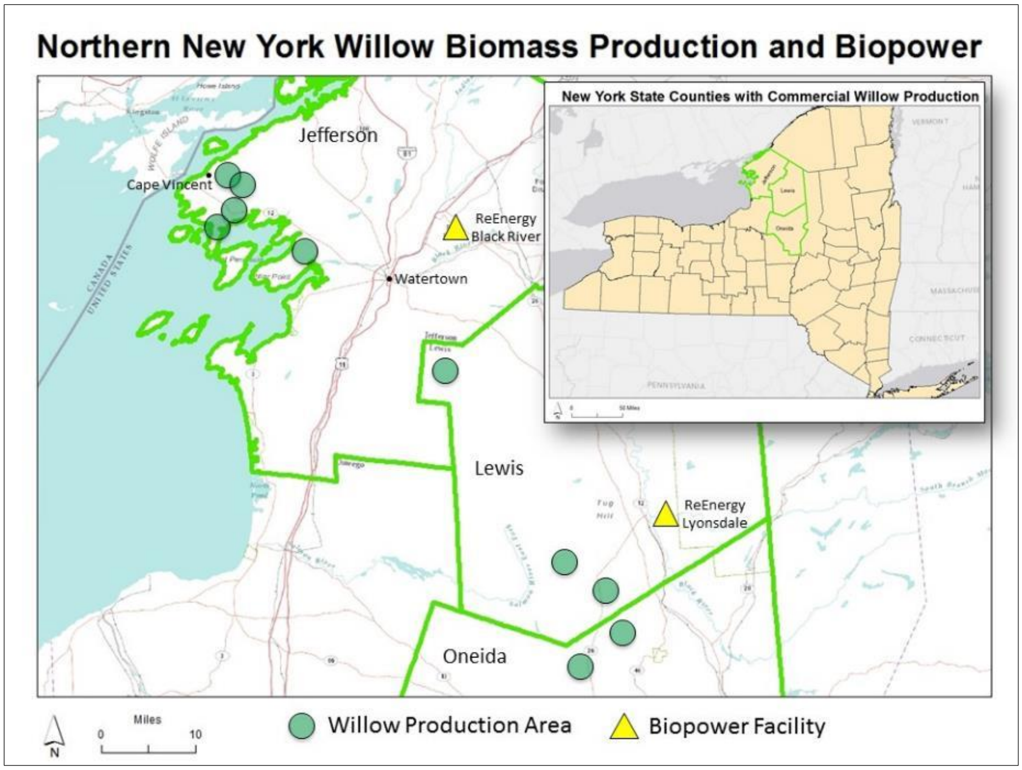

Figure 1: Willow biomass production areas enrolled in USDA BCAP project area 10 and ReEnergy biopower facilities in northern New York State.

	Area Contracted	Planted 2013	Harvested 2013	Harvested 2014	Replant 2015
New Acreage	836.9	836.9	0	0	69.8
Previously Est. Acreage	351.0	0	130	~40	0
Total	1187.9	836.9	130	~40	69.8

Table 1: Summary of willow biomass crops enrolled in the USDA BCAP project area in northern NY State.

New Acreage

The majority of new acreage (planted 2013) in the NY willow BCAP project area was coppiced (cut back) by growers over the winter and early spring of 2014, in accordance with the recommended practice, to encourage more stems per plant and more vigorous growth (Figure 2). Some newly established crop areas have been affected by weed and pest pressures since planting, but crop monitoring efforts by SUNY-ESF and timely action of growers to implement appropriate management activities limited detrimental impacts on the crop. Large crop areas across several fields that had high levels of competing vegetation in summer of 2013 responded well to herbicide applications in mid- to late-summer of that year to control a variety of broad leaf weeds, allowing willow to quickly dominate these areas after coppice in 2014.

Figure 2: Coppiced willow in the northern New York BCAP project area in spring, 2014. Cutting plants back after the first growing season takes advantage of willow's natural coppice ability to regrow more vigorously and produce more stems on each plant from the cut stools and established root system.

During the 2014 growing season, about 500 acres were sprayed with herbicide to control the growth of competing vegetation, mainly perennial grasses previously grown on some fields. Herbicides were effective in deterring the growth of these grasses, allowing willow to gain dominance in the majority if fields by mid-summer. The majority of acres sprayed with herbicide were also treated with pesticide to control leaf sawfly, which was spotted early in the growing season and can severely defoliate and delay young willow crops if left untreated. Pesticide treatments effectively limited damage to the crop. Crops that were observed to have been damaged by deer browse in 2013 recovered well in 2014 due to willow's natural coppicing ability to regrow from cut or damaged stems. The overall objective of vegetation management for willow biomass crops over the first several growing seasons is to enable the willow to dominate the site. Willow was able to achieve dominance over competing vegetation on the majority of newly planted acreage in 2014 and will form a closed canopy during the 2015 growing season, shading out substantial weed competition (Figure 3). Headlands on a portion of fields were mowed in 2014 to maintain access and suppress woody vegetation. One 36 acre field was amended with nitrogen and phosphorous to increase soil fertility and pelletized lime to raise soil pH based on soil test results collected in 2013 by SUNY-ESF and Cato Analytics, and the observance of slower than normal growth rates early in the 2014 growing season and the previous year. More details on these activities are provided in the crop monitoring section of this report.

Figure 3: Example of natural control of competing vegetation achieved by the high planting density and closed canopy of a mature willow crop on previously established acreage in the northern New York BCAP area. The pictured crop was harvested in 2014 and will quickly reform the closed canopy from coppice regrowth on the mature root system in the second harvest rotation.

Crops responded well to these management activities and exhibited good health and productivity throughout the 2014 growing season. By the end of the growing season, the majority of crops on new acreage were between four to eight feet in height (Figure 4), some slightly taller or shorter, with good branch density and sufficient survival and resulting plant density. A fairly wide variation in willow productivity and competing vegetation was observed throughout the growing season between farms, fields, and within some individual fields. This type of variation has been documented in research trials in North America (Volk et el. 2011) and commercial willow production in Europe (Nord-Larsen et al. 2014) and is therefore not unexpected across widespread commercial-scale acreage, especially over the first harvest rotation, due to differences in soil types, site preparation, other environmental conditions, site-cultivar interactions, management activities, competing vegetation and previous land use history. Despite this variation, the majority of newly planted crops are on schedule to be harvested on the normal three- or four-year rotation cycle, while a smaller portion of crops may benefit from additional growing seasons over the first rotation, which will help to further stagger and balance annual harvests.

Figure 4: The majority of willow crops on newly planted acreage in the BCAP project area were four to eight feet tall by the end of the 2014 growing season (one-year-old stems on a two-year-old root system), representing expected productivity and normal levels of variation across large acreage with different soil and environmental conditions, management practices, previous land uses and other factors from site to site. Crops pictured in this field were about four feet tall in June, 2014.

Some crop areas displayed excellent growth, up to ten feet in height and a fully closed canopy just two growing seasons after planting, and may be ready for harvest on a shorter than normal rotation cycle or produce especially large quantities of biomass. Other relatively small areas displayed less than optimal growth, possibly as a result of soil limitations such as available rooting volume, depth to root restricting layer, or limited water holding capacity. These areas may need additional management activities or extended rotation lengths to produce adequate biomass and will be monitored and managed appropriately in 2015.

No additional acreage was planted or replanted in 2014, but several areas totaling 69.8 across two farms in the Cape Vincent, NY area were targeted for replanting in 2015. These areas were primarily identified by growers, and staff at SUNY-ESF confirmed that plant density on the majority of these areas was likely too low to ensure a productive crop. The low density was mainly a result of above average rainfall during spring and early summer of 2013 that created wet ground conditions and delayed field operations of the initial planting into July, beyond the recommended planting window for NY State when temperatures become too hot and quickly dry out young willow cuttings before they can establish a root system to support aboveground growth. This primary limitation likely contributed to other factors hindering survival in these areas which will be considered during replanting efforts such as marginal soil qualities in some spots and inadequate size of cuttings at the time of planting which were unable withstand hot weather shortly after planting. SUNY-ESF, in cooperation with growers and officials at ReEnergy, drafted a proposal for funding assistance to replant willow crops in these areas. If approved, these areas will be prepared and replanted in the spring of 2015.

Mature Acreage

About 130 acres of mature crops (planted 2008 and prior) contracted under this BCAP project were harvested and delivered to ReEnergy Lyonsdale NY in 2013. Coppice regrowth on these harvested acreages was monitored throughout the growing season by SUNY-ESF. Regrowth from the cut stools and well-established root system was vigorous and quickly filled in the willow canopy (Figure 5), controlling competing vegetation and allowing the willow to dominate the site and maximize productivity. By the end of the 2014 growing season, the majority of crops on these previously harvested acreages were six to eight feet in height, on par with expected growth rates, with good branch density and high plant survival. No major incidents of competing vegetation, pests or diseases were identified. The crops on harvested acreage are now on target to be harvested again on a three- or four-year rotation cycle.

Figure 5: Second rotation coppice regrowth in June, 2014 on previously established willow fields in the northern NY BCAP project area. The well-established root system and natural coppice ability of willow allowed these plants to quickly dominate the site in 2014, after harvest the previous fall.

2. Crop Utilization Status

In 2013, about 2,477 tons of willow was harvested and delivered to ReEnergy Lyonsdale which produced about 1,400 Mwh of renewable electricity, enough to power approximately 130 homes for an entire year. Analysis of these harvested willow chips showed that critical quality indicators of moisture, ash and energy content were within acceptable ranges for current end-use applications with very low levels of variation (Conable et al. 2013). The willow feedstock was successfully mixed and combusted with forest residues and other biomass sources to produce biopower and heat without complications. In 2014, about 540 tons of mature crops contracted under this BCAP project were harvested from fields near Barnes Corners, NY (Figure 6) and delivered to the ReEnergy Black River facility on the Fort Drum Army Base near Watertown, NY. About 40 tons of biomass was also harvested from fields near Ava, NY, and delivered to ReEnergy Lyonsdale before weather and ground conditions forced harvesting operations to be put on hold before the end of 2014.

Project staff at SUNY-ESF collected a limited number of chip pile samples from these harvesting operations in 2014 and analyzed the samples for moisture content. Harvested chips were sampled on four separate days and moisture content varied based on precipitation and time since harvest. Mean

Figure 6: Harvesting operations conducted by the Celtic Energy Farm on BCAP willow in October of 2014 near Barnes Corners, NY.

moisture at Barnes Corners was 42% on 10/2, 53% on 10/8 (rain), 48% on 10/17. Mean moisture at Ava was 49% on 10/8 (light rain). There was also a 4% to 9% difference in moisture content between shallow (<50 cm) and deep (>50 cm) samples within the large chip piles created by the collection vehicle dump wagons. This information is being used to develop more advanced and accurate chip sampling procedures for future harvests. Overall, the distribution of moisture values (Figure 7) was within the expected ranges based on previous sampling efforts of commercial-scale harvests conducted in 2013 and 2012 using the same New Holland 9000 series forage harvester make and 130-FB woody crops cutting head. Harvesting in 2014 was conducted with some leaves still on the branches and in above-freezing temperatures to take advantage of suitable ground conditions, which may have contributed to higher moisture contents. Overall, chip quality is expected to meet the quality standards for the current end-use as they did in 2013, and willow chips have shown consistent quality properties and very low variability in recent studies of commercial-scale willow (Eisenbies et. al 2014).

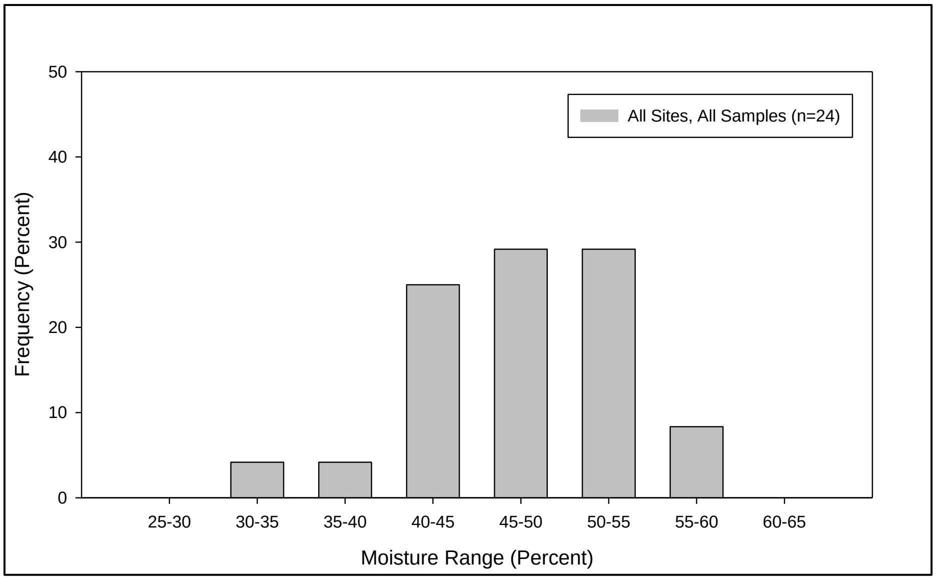

Figure 7: Distribution of moisture content of commercially harvested willow chips across two sites and four sampling dates in October, 2014.

Additional areas of previously established and now mature willow crops, are scheduled to be harvested in 2015. By 2016 and 2017, some newly established cops will likely be ready for first-harvest and mature crops harvested in 2013 will be nearing the end of the second rotation. Thus, several hundred acres of commercial willow crops will likely be available for harvest and utilization in the project area annually in 2015 and beyond. This level of willow biomass will be a substantial increase in production, yet will still represent only a small fraction of total biomass feedstock demand for the two ReEnergy facilities in the region. Higher percentages of willow could be integrated into this feedstock supply chain if willow acreage were to be increased. Willow delivered to ReEnergy Lyonsdale in 2013 was piled separately by plant operators then carefully mixed with the other feedstocks at various rates using a loader. This method of careful mixing and monitoring proceeded without incident giving plant operators a degree of confidence in the willow feedstock such that future willow loads are not to be piled separately in the yard but are instead being immediately combined with other woody feedstocks upon delivery to this facility.

ReEnergy Black River recently signed a 20 year contract to supply 100% of the electricity to the Fort Drum Army Base, ensuring stable long term demand for woody biomass (http://goo.gl/Sbtv1z). ReEnergy Lyonsdale received a three-year contract extension through the New York State Energy Research and Development Agency (NYSERDA) and New York's Renewable Portfolio Standard. Access to harvesting equipment in the BCAP project region, including a New Holland self-propelled

forage harvester and 130-FB woody crops cutting header, is being facilitated via Celtic Energy Farm, the Northeast Woody/Warm-season Biomass Consortium (NEWBio) and SUNY-ESF. Two specialized willow planters are also available under the NEWBio program if additional opportunities to plant large acreage become available again in the near future.
http://www.newbio.psu.edu/Extension/willowEquipmentAccess.asp

3. Extension Services

To assist BCAP growers and other stakeholders in the expanding willow industry in New York State, SUNY-ESF, with support from NYSERDA and NEWBio, is providing a range of technical, analytical and educational extension services. Some highlights of these activities from 2014 are provided below.

Crop Monitoring

Staff from SUNY-ESF assisted BCAP growers throughout the 2014 growing season with crop monitoring efforts conducted across the 836 acres of new crops and 351 acres of previously established crops. At the beginning of the growing season, staff provided growers with data analysis and management recommendations based on soil sampling and plant density studies conducted in 2013. This information was presented in the form of written reports and field maps created from GIS analysis of interpolated data collected by project staff, and was discussed with growers by phone, email and in-person meetings. It was determined from this information, discussions, additional observations and decisions by growers that the majority of newly planted acreage had sufficient plant density, aside from the 69 acres of crops targeted for replanting in 2015 described above.

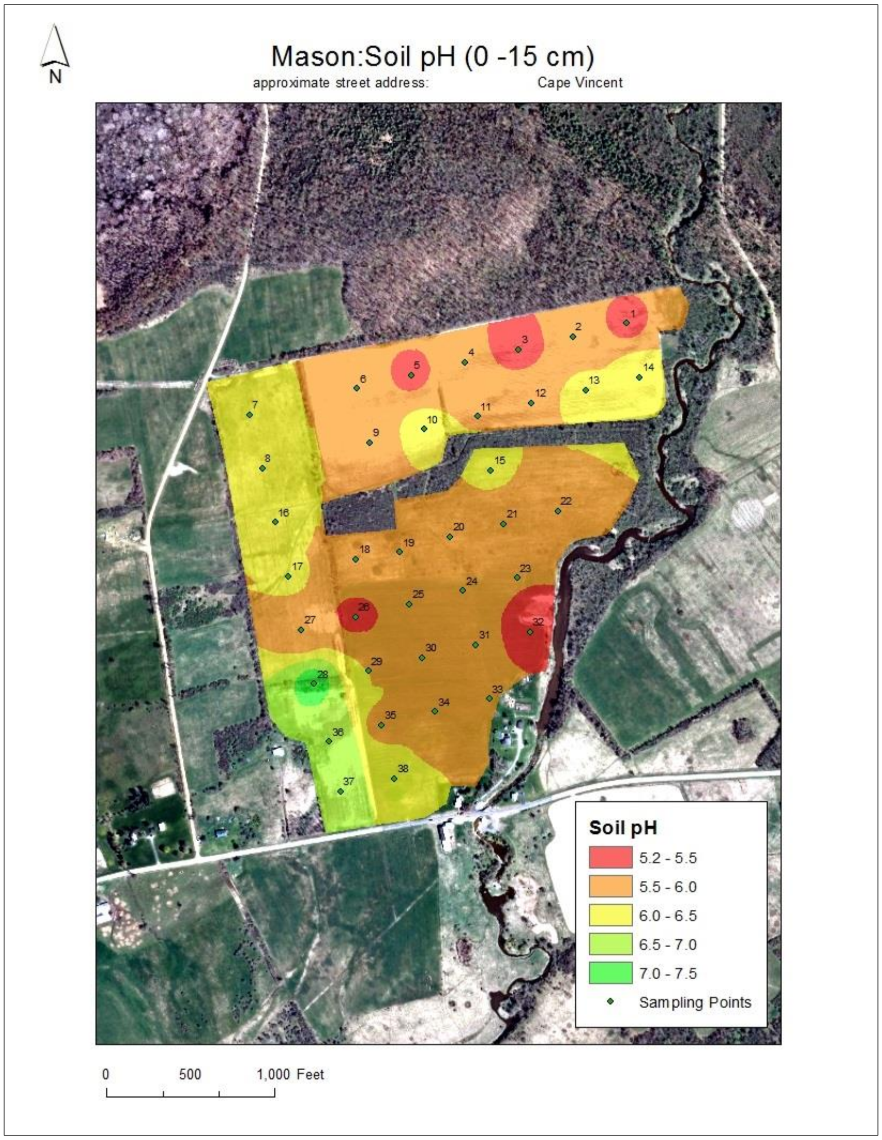

Figure 8: GIS map of soil properties created in 2013 and used in 2014 to assist willow growers with crop management decisions regarding soil amendments and replanting.

A review of existing literature and willow producers' handbooks was conducted by SUNY-ESF in regards to the topic of fertilizing willow based on soil test results. Available information on this topic is limited and often conflicting, but project staff were able to develop basic guidelines for fertilization of willow using documented rates of nutrient removal in harvested biomass, rooting depth and other ecophysiological traits of willow biomass grown in a multi-year rotation. This analysis allowed SUNY-ESF to provide growers with basic recommendations for fertilization based on minimum fertility levels in soil test results, below which a nutrient limitation would be likely to negatively impact yield. This analysis and interpolated GIS maps of soil test results (Figure 8) were presented to growers early in 2014. Based on this information and the management objectives of growers, it was decided that the large majority of crops would not be fertilized at this time based on the soil test results provided by SUNY-ESF and Cato Analytics, the high financial and energy costs of purchasing and applying amendments, and the uncertainty of response in biomass yield to fertilizer treatments (Hangs et al. 2008, Quaye et al. 2013), especially in the first or second rotation.

One 36 acre field of newly established crops was selected for amendments which consisted of pelletized lime (0.7 ENV) applied at a rate of 6 tons per acre to raise pH, nitrogen applied at a rate of 100 pounds N per acre equivalent and phosphorous applied at a rate of 50 pounds per acre equivalent (35-17-0 N-P-K) to increase soil fertility. The impact of these amendments was notable over the course of the growing season as willow crops which had clearly underperformed in 2013 and early 2014 (based on visual observations) quickly resumed expected growth rates after amendments were applied and finished the growing season with similar height and vigor of nearby fields (Figure 9).

Figure 9: The response to liming and fertilization was notable on the 36 acre field that was selected for amendments based on observations, soil test results, crop monitoring, GIS mapping, and discussions with growers. Crops in this field were showing clear signs of nutrient deficiencies in late June, 2014 (left) but responded well to amendments with a rapid increase in growth rates that produced plants four to six feet tall (right) by the end of the growing season.

SUNY-ESF continued to meet with growers in the field and interact with them by phone and email on a regular basis throughout the 2014 growing season to discuss the overall health and vigor of the crop; issues with competing vegetation, pests and other potential stressors; appropriate management practices; and the effectiveness of the crop management activities undertaken. Crop monitoring efforts were advanced through the use GIS technology integrated with digital photography to create interactive maps of geo-tagged photos across the landscape (Figure 10), allowing growers to easily view the status of the crop and places where increased management may be needed over a wide geographic area with relative ease. This technology and innovative crop monitoring technique was useful in identifying and monitoring competing vegetation and outbreaks of leaf sawfly and evaluating the effectiveness of controls to these stressors throughout the growing season, limiting their pervasiveness and impact on the crops. A more detailed description of this crop monitoring technique and results is available at the web address: http://nebioenergy.blogspot.com/2014/09/assisting-bioenergy-farmers-using-new.html

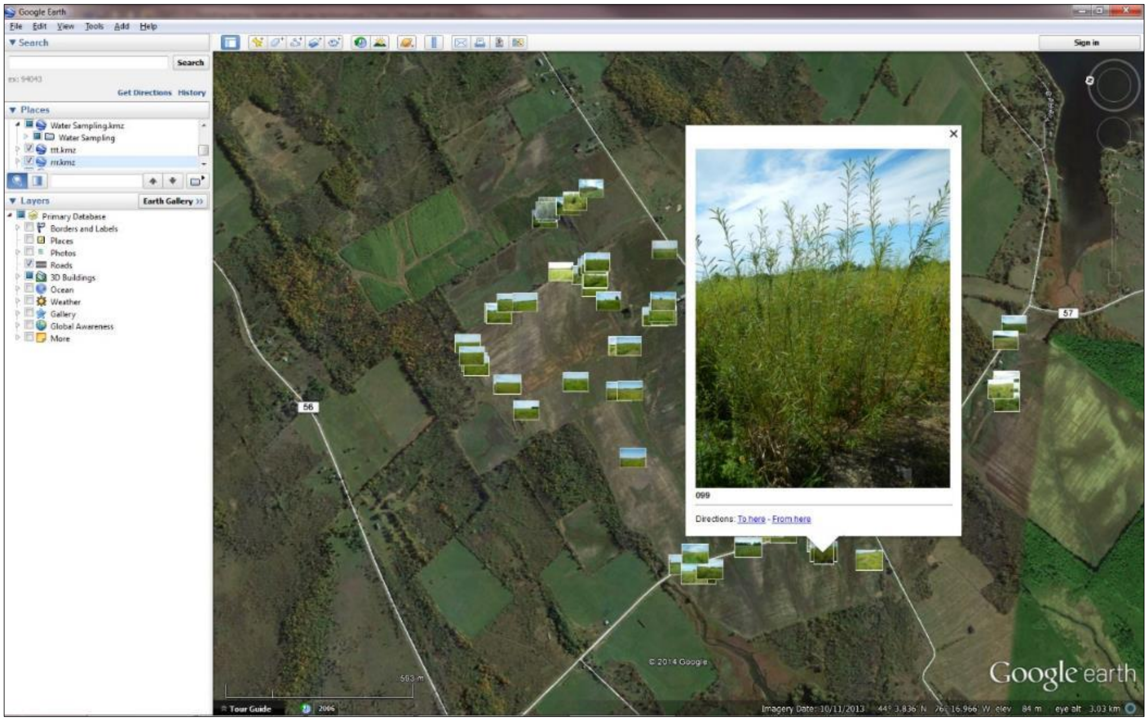

Figure 10: A series of geo-tagged photos across five hundred acres of willow crops in the BCAP project area in northern New York State, displayed in the Google Earth software program. Each thumbnail on the map can be expanded to provide visual reports of crop conditions, weed and pest pressure, and other visual information in precise locations across large areas.

Financial Analysis Tools

SUNY-ESF's model for the economic analysis of shrub willow crops EcoWillow v1.0 was downloaded by over 1000 users in 70 countries around the world from 2008-2012. In 2014, EcoWillow 2.0 was comprehensively updated using feedback from willow producers and other stakeholders, the most up-to-date data collected from commercial willow operations in the NY BCAP project region, and the latest research by SUNY-ESF and partners. Key updates to the model include a new "fields module" for more precise analysis of transport distances and planted areas across numerous field locations, an updated harvesting module, outputs in both wet and dry biomass, advanced capabilities for modeling the impact of BCAP and other incentive programs, and a more user friendly design (Figure 11). Three fact sheets to support the use of EcoWillow 2.0 were also created and released: a summary of updates to the model; an introduction to the layout and use of the model; and a scenarios fact sheet that details the inputs and outputs of four example (hypothetical) crop production scenarios using the model.

The EcoWillow model will continue to be promoted and updated based on additional feedback received from BCAP growers and other stakeholders. In February of 2015, SUNY-ESF will present an instructional webinar on EcoWillow 2.0 hosted by the NEWBio project. All of this information is available in more detail on the willow webpage: www.esf.edu/willow/download.htm

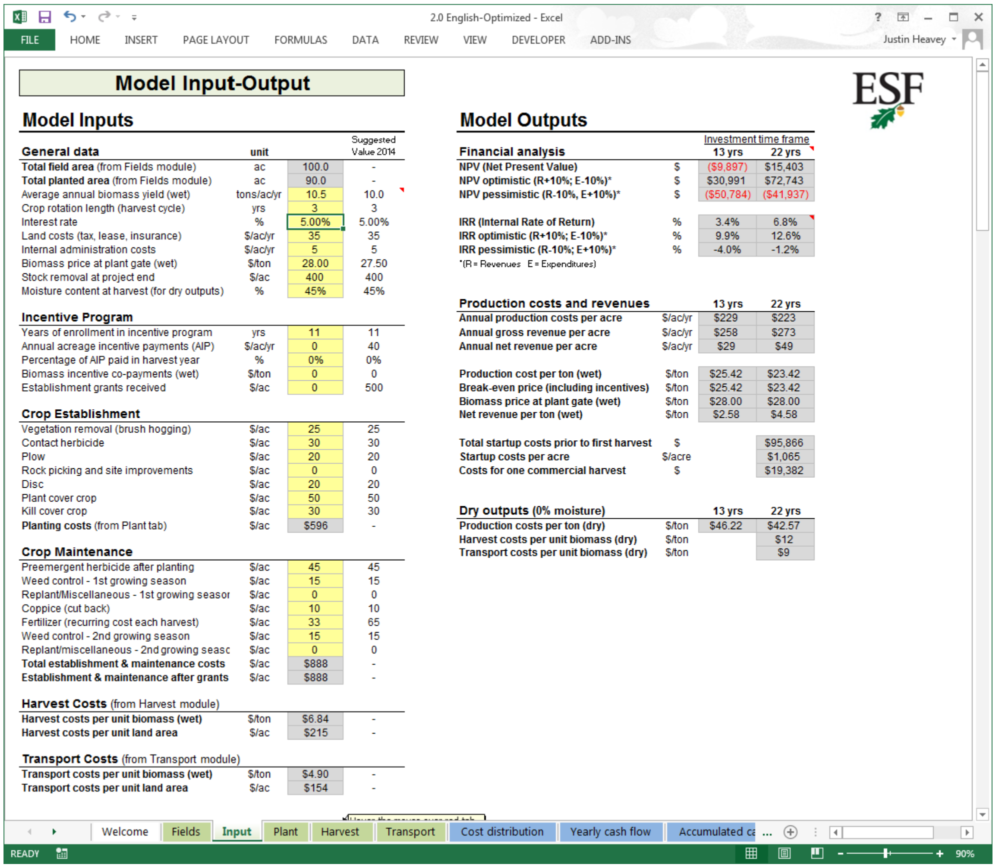

Figure 11: The redesigned Input-Output module of the EcoWillow 2.0 model under the (hypothetical) improved production scenario.

Staff at SUNY-ESF also contributed to an enterprise budget model for willow biomass in 2014 developed by the NEWBio team to serve as a simplified "first look" at the economics of the crop before proceeding to more detailed analysis using EcoWillow. That model and supporting documentation is available for download from the following web addresses.

http://extension.psu.edu/natural-resources/energy/field-crops/resources

Education and Outreach

To support the ongoing education of current and potential willow producers and end-users, SUNY-ESF drafted several willow extension publications in 2014 including a new full-color introductory brochure, four research summaries, three fact sheets, and three articles published in “Willow and Poplar News”. SUNY-ESF also created a suite of new tabling materials for use at willow outreach events including a new crop production diagram, informational signage, photo displays and hands-on materials such as sample wood chips, wood pellets and cut willow stems of various ages. These educational materials were used at several events throughout the year and will continue to be used for future events and updated as necessary. Extension publications are available for download from the following web address (http://www.esf.edu/willow/pubs.htm).

SUNY-ESF hosted and participated in a range of outreach events in 2014, in and around the BCAP willow region including guided tours of willow plantings; presentations to students at SUNY Cortland, Jefferson-Lewis BOCES and Belleville-Henderson High School; a career fair in Watertown, NY; events held at SUNY-ESF related to National Bioenergy Day, presentations at local conferences including the annual North Country Clean Energy Conference; and others. Several of these events were reported on by local news agencies and the stories can be accessed at the following web address: (http://www.esf.edu/willow/Media.htm#News). Meetings between growers and other willow stakeholders, in the field and at various locations, were coordinated by SUNY-ESF throughout the growing season to discuss crop health, management activities, logistics of crop production and future opportunities to expand willow production and optimize the supply chain. Staff at SUNY-ESF and Cato Analytics organized and met with willow growers, biomass end-users, researchers, extension personnel and other stakeholders in numerous teleconferences, meetings and conferences throughout 2014 including the NEWBio annual meeting held in Geneva, NY which included tours of willow research plots where improved willow cultivars are being tested for biomass production, disease and pest resistance among other traits.

In partnership with NEWBio, SUNY-ESF also engaged in numerous outlets of digital communications to disseminate the latest research and commercial developments of willow biomass in New York State including a comprehensive update to the ESF Willow Project website, YouTube videos, webinars, social media, eXtension.org Farm Energy Site, electronic newsletters and more. Links to these online resources are provided below.

- ESF Willow Website: http://www.esf.edu/willow/
- Videos: http://www.esf.edu/willow/Media.htm#Videos
- Webinars: http://www.esf.edu/willow/Media.htm#Webinars

- Twitter: https://twitter.com/NEWBioProject
- Farm Energy: http://www.extension.org/pages/71100
- E-News Letter: http://www.esf.edu/willow/Media.htm#Enews
- Bioenergy Extension Blog: http://nebioenergy.blogspot.com

Research

SUNY-ESF continued research and development in many of the areas directly applicable to the growing willow industry and bioeconomy in northern New York, including harvesting and logistics, willow chip quality and variability, environmental sustainability, and feedstock improvement. Data collected from planting and harvesting operations was applied to the revised EcoWillow model, crop production scenarios and other analyses that are currently underway. A series of sampling plots were established in several of the BCAP willow fields (Figure 12) to begin monitoring water quality, water quantity and greenhouse gas emissions on commercial willow acreage. These plots were set up in both newly planted and previously established acreage and will be monitored over two growing seasons to capture seasonal variation in a range of willow age classes. Sampling plots were also established in nearby corn and hay fields for comparison of willow to traditional agricultural crops grown in the region.

Figure 12: Sampling plots were established in several fields in the BCAP project area in 2014, like this large stand (one-year-old stems on a two-year-old root system) to begin measuring water quality, water quantity and greenhouse gas emissions in commercial willow.

As part of the effort to support the expansion of willow biomass crops in the region, SUNY-ESF initiated an analysis of suitable land potentially available for willow biomass production in a five county region around the two operating ReEnergy facilities. Data layers including land cover and tax parcels from each county were used for the preliminary assessment. Suitable parcels had to be greater than 20 acres (8 ha) in size, and have a land cover class of barren land, shrub/scrub, herbaceous, hay/pasture, or cultivated crops. Preliminary results showed that there are over 820,000 acres that could be used to grow willow (Figure 13). The next steps in this process will be to add additional data layers of biophysical conditions such as slope and soil types to indicate site suitability. Funding is being sought to hold face-to-face meetings with a sample of landowners from the region to better understand their interest in willow and at what price points they would be willing to engage in production.

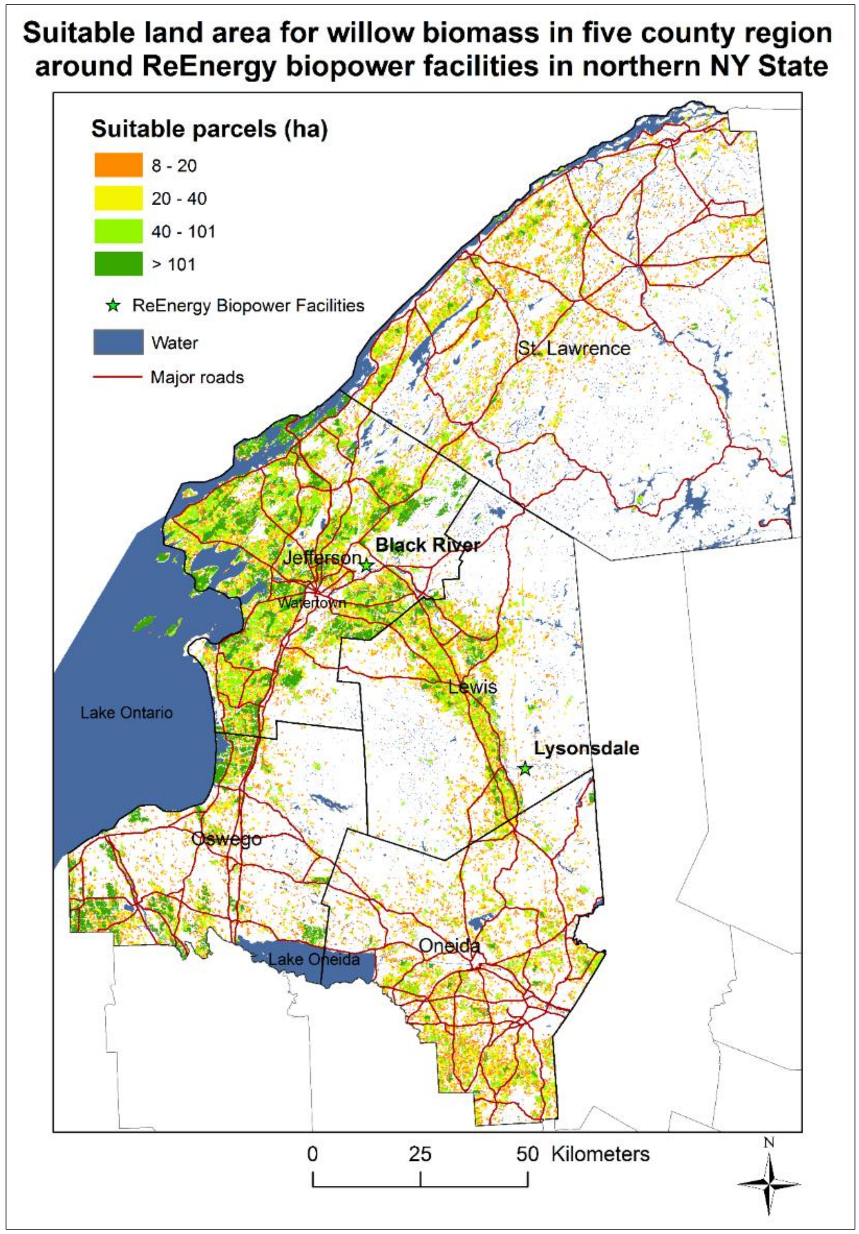

Figure 13: GIS map of a preliminary assessment of suitable land parcels over 20 acres (8 ha) in size hat may be available for willow biomass production in parts of the current BCAP project region.

Another GIS research project was undertaken at SUNY-ESF in 2014 through the NEWBio BioEnergy Scholars program that involved mapping crop boundaries of willow fields in the BCAP project area and comparing the resulting crop area to total land area within each tax parcel or leased land area including headlands, hedgerows, ditches or other areas left unplanted. The primary purpose of this analysis is to evaluate the land use patterns in commercial willow acreage and improve field design and crop management practices to increase economic efficiency and environmental sustainability. This research is also contributing valuable information to the GIS database that SUNY-ESF is developing for commercial willow fields in the project region and assisting with other analyses and logistics by more explicitly defining the spatial boundaries of the crop production areas. More data related to this project will be collected and analyzed in 2015.

In December of 2014, SUNY-ESF and several partners were awarded a new research grant from the U.S. Department of Energy up to $3 million to continue research aimed at optimizing willow harvesting and logistics and improving the economic efficiency of these operations (http://goo.gl/3nW6ww). Much of this work will be conducted on willow fields in the BCAP project area as research and development of the current harvesting technology and field operations is further studied in commercial settings. These efforts will further optimize harvesting and logistics of the supply chain while monitoring and maintaining the quality of the biomass. This should help growers lower harvesting costs and ensure that end-users receive consistent quality of willow feedstock. This research, combined with ongoing and future studies, will contribute to sustainability assessments, lifecycle and techno-economic analyses, stakeholder engagement and the continued advancement of the willow biomass industry in New York State and the northeast. Several peer-reviewed journal articles on these and related topics authored by staff at the SUNY-ESF Willow Project were published in 2014 and are available at the following web address (http://www.esf.edu/willow/pubs.htm/#a2014)

4. Future Activities 2015

If funding is approved, growers hope to replant the 69 acres identified as having insufficiently low plant density in the spring of 2015. Delays in harvesting operations due to wet field conditions in fall of 2014 will make harvesting operations a priority for growers in winter of 2015 and the following fall/winter. SUNY-ESF will continue to assist growers with crop monitoring and management tasks and meet with growers and other stakeholders in the field as needed to provide information and technical assistance. Efforts will continue, with support from NYSERDA and NEWBio, to provide a range extension services and disseminate the latest information and educational materials. Ongoing research projects at SUNY-ESF to support commercial willow production will continue and additional projects may be undertaken as well. Staff at SUNY-ESF and Cato Analytics will continue to work closely with growers, biomass end-users and other stakeholders for the advancement of the willow biomass industry in the region. If additional BCAP funding should become available, ReEnergy Holdings will review the possibility of contracting for increased willow plantings within the project area. The current feedstock demand from the two operating biopower facilities in the region is many times the quantity of willow biomass that will be delivered from the current BCAP project acreage, and large additional amounts of willow could likely be incorporated into the feedstock stream without complications. Previous and recent assessments of available land area immediately around the two ReEnergy biopower facilities show substantial land area suitable for willow biomass crops that could potentially be available for expanded commercial acreage. Increasing willow biomass production over the next several years will strengthen and advance the regional industry and have numerous benefits including increased integration and synergies with other feedstocks for biopower, the development of additional markets and end-use applications such as pellet production and bioremediation of municipal wastes, an expanded network of regional stakeholders, further innovations across the supply chain, additional research opportunities, and integration with other landscape elements for multiple environmental, economic and social benefits.

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