Regional Feedstock Partnership: Woody Crops

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Feedstock Supply and Logistics

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Project Overview – Woody Crops

- DOE and the Sun Grant Initiative formed the **Regional Biomass Feedstock Partnership** in 2007
- Regional Biomass Feedstock Workshops
- Conduct a literature review to establish the current state of technology for major woody crop candidates
- Establish field trials to evaluate new varieties on representative sites around the country
- Produce new, elite genotypes for improved process performance
- Assess yield data, including long-term production patterns
- Provide data to the KDF for public consumption

**Woody Resources**

*Sun Grant Lead:* The University of Tennessee

*Agency Lead:* ORNL; Department of Agriculture
Management Approach

**Willow Development Team**

Tim Volk, Lead
SUNY-ESF
Ray Miller – Michigan State University
Lawrence Smart – Cornell University
Tom Corbin – Middlebury College
Julia Kuzovkina – Univ. of Connecticut

Collaborators: Belleville Henderson Central School, Celtic Energy Farms, Double A Willow, Middlebury College, SUNY Potsdam, University of Illinois, University of Minnesota, SROC, USDA NRCS Big Flats

**Poplar Development Team**

Bill Berguson, Lead
UMN, NRRI
Mike Cunningham – ArborGen, Inc.
Randy Rousseau – Miss. State University
Bernard McMahon – UMN, NRRI

**Advisory Team**

Bryce Stokes – CNJV, LLC
Marilyn Buford – USDA, Forest Service
Jim Perdue – USDA, FS – Southern Res. Station
Don Riemenschneider – USDA, FS (ret.)

**68 Total Sites**

- Genetics tests
- Yield trials
- Nurseries
Technical Approach

1. Advance genetics & breeding program
2. Establish replicated field trials for new varieties (poplar & willow)
3. Incorporate existing field trials for current baseline yields
4. Populate the KDF with current yield data

Crop Development
- Woody crops (poplar & willow) offer significant genetic variation to draw on for advancement
- Presents the prospect of tailoring crops for optimal conversion

Sustainable Production
- Woody crops fulfill the need for a portfolio of feedstock sources to:
  1) Minimize supply chain disruptions
  2) Diversify the landscape, and
  3) Maximize ecological and environmental benefits

Harvest Systems
- Woody crops provide material for diverse markets
- Flex management targets the range of landowner interests and objectives

Supply & Logistics
- Woody crops provide an important approach to address annual supply issues
- The supply chain infrastructure is in place due to FPI
1 Year Crop Establishment

Site Preparation

Planting

Coppice (Cut-Back)

Three Years Growth

Minor Maintenance

Rapid Regrowth

Harvest Biomass

7 Crop Cycles

7 Harvests

25-35 Wet Tons/Acre

1 Year Crop Establishment
• First U.S. willow trial to be harvested over seven rotations
• Relative growth rate of top cultivars ranged from 120 – 170%
  ○ Across all cultivars it was 104% to 129%
• Provides data to support assumption of long term productivity of willow systems

Relative growth rate of willow cultivar SV1 over 7 rotations. First rotation yield is baseline for relative growth calculations.
Impact of New Cultivars

Willow Cultivars in Trials

- Trials established in 2005 and beyond include cultivars developed in breeding programs in NY
- For top five cultivars survival of new material was 16.3% greater and yield was 34% higher
- Picture to right is 3-year old prior to harvesting

Changes in Yield Over Time

- Continuous funding provided the first set of multiple rotation data for new cultivars
  - Across 5 sites for both two (Sleight et al. 2016) and three rotations (Sleight and Volk 2016)
- Revealed important patterns about long term yields
  - High yield cultivars have smaller increase from 1st to 2nd rotation
  - Yields of good cultivars are high and consistent over three rotations
- Changes in yield from 1st to 2nd and subsequent rotations are crucial to modelling yields, LCA, and economic projections
Changes in Yield are not consistent across the range of first rotation yields but can be ~200% (Miller 2016).

Models developed to predict 2nd rotation yield using 1st rotation yield and site factors has $R^2=0.69$ (Sleight et al. 2016).

Essential to understand for economic and environmental impact analysis.

Percent change in yield from first to second rotation based on first rotation yield across willow plots at five sites (Sleight et al. 2016)
Yield Over Three Rotations

- Top five cultivars varied by site and from 1\textsuperscript{st} to 3\textsuperscript{rd} rotation.
- Selections after 3\textsuperscript{rd} rotation from the same site gave highest yields.
- Picking cultivars from the 1\textsuperscript{st} rotation from a different site reduced yield by 11 – 14\% and NPV by 18 – 50\% over 22 years.
- In MI selecting site specific cultivars increased biomass by 2 – 13\% and picking cultivars from a distant site reduced biomass by up to 27\% (Miller 2016).

Changes in ranking of 18 willow cultivars over two rotations in Belleville, NY (Sleight and Volk 2016)
Impact of Willow Yield Trials

- Best cultivars are licensed to commercial nursery in NY (Double A Willow) for large scale production
- Data used to patent one new willow variety in U.S. and plant breeders rights in Europe and Canada
- Trial data incorporated into national yield map and recently released version of EcoWillow model used for economic analysis
Willow in Northern NY

- >7,200 tons of willow chips delivered
- Willow found to be suitable fuel in terms of moisture and ash content, now incorporated with other feedstocks
- Existing willow acreage will produce roughly 9,000 – 11,000 Mg\text{wet} of feedstock annually
Additional Impacts

• Yield trials have been used extensively for outreach and education events
  o Continue to be used as sites for these activities
• High school and college students have used sites for classes and experiments
• Series of fact sheets and research summaries have been created ([www.esf.edu/willow](http://www.esf.edu/willow))
Poplar Field Trial Network

**Clone Screening**
- Evaluation of existing clones from each region to determine variation in growth rate and disease resistance

**Genetic Improvement/Breeding**
- Using unique resources of the Poplar Team, develop new hybrid and pure-species clones for future testing and commercial deployment

**Yield Analysis**
- Under conditions resembling commercial plantations, evaluate long-term production of poplar using currently-available genetics
Clone Test in Minnesota – Age 10

• Created one of the largest collections of new clonal material in the world adapted to northern climates
• Expanding breeding for southern regions using the best parents with proven performance in the South

• Largest network of field tests including clone test and biomass yield studies in US
Partnership Poplar Breeding

• Can we exceed the yield of commercial standards while maintaining disease resistance?
• Can we increase genetic diversity while maintaining growth rate?
• What is the long-term potential to increase volume growth with successive cycles?
• What is the most productive breeding design for long term success?
• Results:
  o Produced over 10,000 new genotypes as a source for future clone testing
  o Providing clones to cooperators
• Operation of our breeding program allowed heretofore impossible studies of inheritance and genetic effects in controlled-pollinated populations in “Family Field Tests”.
• Four sites, four taxa - P. deltoides, P. deltoides x nigra, P. maximowiczii and P. nigra.
• Typically 900 genotypes, 30 families with 30 clones within-family replicated three to five times per clone
• **Question:** Why should anyone fund breeding? What is the expected gain and how do you get there?

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**Variance Component Analysis - Genetics**

- **Clone/family variance**
- **Family variance**

**Proportion of Total Genetic Variance by Component by Taxa**

- **P. deltoides x P. deltoides**: 92.2%
- **P. deltoides x P. maximowiczii**: 104.2%
- **P. deltoides x P. nigra**: 392.6%
- **P. nigra**: 305.7%

**Long-term Yield Gain = 17.5 to 25.2% each generation by improvement of parents and crossing within improved parents**
Breeding Opportunity

- Given the high natural variation among native P. deltoides and P. nigra collections, selection of high-yielding parent will result in high differentiation and,
- Our new knowledge of additive genetic effects indicates that hybridization among elite genotypes will “carry over” thereby capturing yield gain with each generation.
Yield Testing

• New clones surpassing current commercial clone by a significant margin
• Yields in Midwest are is 3.5 to 5 tons acre\(^{-1}\) yr\(^{-1}\)
• Yield in Pacific Northwest, Mid-South and South – 4.5 to 6.5 tons acre\(^{-1}\) yr\(^{-1}\)
• Provided data to yield mapping effort

*Photo courtesy of Steve Thomas, DOE-BETO*
Poplar: Summary

- Clone trials show that gains of 1.3 to 1.5 over current commercial hybrids possible
- Tests of P. deltoides and P. nigra clones in both Midwest and Mid-South show that DxN hybrids most likely the most productive and disease resistant
- P. nigra adaptability tests in Minnesota, Washington, Mississippi, South Carolina, Tennessee and Virginia
- No shortcuts in field testing – four years needed for initial selection plus additional monitoring in subsequent years
- Yields currently in the range of 3.5 to 7 tons acre\(^{-1}\) yr\(^{-1}\)
- Economics in the range of $70 to $90/dry ton delivered – within DOE target range
- Produced over 10,000 new genotypes as a source for future clone testing
- Developed a new understanding of genetic effects and most efficient design of future breeding programs