Willow Biomass Crops for Bioenergy and Bioproducts

T. A. Volk¹, L. Abrahamson¹, T. Amidon¹², J. Howard²

¹SUNY-ESF, Syracuse, NY
²Applied Biorefinery Sciences, Syracuse, NY

BioPro Expo, Atlanta, GA, March 14 – 16 2011
Colleagues and Collaborators

- **SUNY - ESF**
  - Dr. Thomas Amidon - Dr. Lawrence Abrahamson
  - Phil Castellano - Doug Daley - Eric Fabio
  - Asif Hasan - Michael Kelleher - Dr. Arthur Stipanovic
  - Dr. Ed White
  - **Graduate Students**
    - Joy Adiele - Jesse Caputo - Renato Pacaldo
    - Amos Quaye
    - numerous undergraduate students

- **Academic Partners and Collaborators**
  - Agrifood and Biosciences Institute - Canadian Forest Service
  - Cornell University - Michigan State University
  - Middlebury College - Montreal Botanical Gardens
  - SUNY Delhi - University of Connecticut
  - University of Guelph - University of Minnesota
  - University of Saskatchewan - University of Vermont

- **Industrial Partners**
  - Agricultural Development Services - AgroEnergie - Antares Inc.
  - Applied Biorefinery Sciences - Case New Holland - Catalyst
  - Renewables - Double A Willow
  - Greenwood Resources - Honeywell International - Mesa
  - Engineering - O’Brien and Gere
Role of Woody Biomass

- Renewables contribute about 7% of the U.S. primary energy supply
- Wood is the second largest source of renewable energy in the U.S. after hydro
- Wood supplies about 2% of U.S. energy needs

U.S. renewable energy sources from 1950 – 2009 (EIA 2010)
Woody Biomass Resources

• Variety of sources ranging from forest biomass to harvesting and manufacturing residues to short rotation woody crops (SRWC)
• Multiple sources will be mixed during the year
  – Limits need for long term storage of feedstocks
  – Consistent year round supply can be maintained
  – Handling and transportation systems developed and in place
  – Just-in-time harvest and delivery
• SRWC and forests are perennial systems with low annual inputs and high potential to generate a broad range of ecosystem services
• In forested regions SRWC are likely to be part of an integrated supply, not the sole source of material
  – SRWC will vary by region of the country and include pine, eucalyptus, hybrid poplar, willow
Sources of Woody Biomass

- Spectrum of systems that can be used to produce woody biomass for biofuels, bioproducts and bioenergy and associated gradients in soil manipulation and silvicultural inputs (After Burger, 2002).
Technically Available Woody Biomass Supply

- Determine amount of technically available woody biomass from forests and willow biomass crops available in 80 km radius around Lyonsdale, NY (Castellano and Volk 2008)

80 km radius woody supply shed around Lyonsdale, NY (Castellano and Volk 2008)
Technically Available Woody Biomass from Forests

- Over 606,000 ha of forest cover
- Remove forest land:
  - preserves
  - excessive slope
  - small parcels
  - classified wetland
- ~ 363,000 ha of timberland
- Potential production of 422,000 odt per year
  - 79% of 80 km radius assessment

Timberland within the 80 km road network around Lyonsdale, NY (Castellano and Volk 2008)
Technically Available Woody Biomass from Agricultural Land

- 209,000 ha of agricultural land cover
- Remove land:
  - not classified for agriculture
  - excessive slopes
  - wetlands
  - small parcels
- ~ 101,000 ha remaining
- On 10% of this land (10,000 ha) could produce 112,000 odt/yr

Agricultural land in a 80 km radius around Lyonsdale, NY (Castellano and Volk 2008)
Technically Available Woody Biomass Supply

- Available land includes
  - 363,000 ha timber land
  - 101,000 ha agricultural land
- A total of 534,000 odt of woody biomass is technically available
  - 422,000 from timber land
  - 112,000 from willow crops
- Willow biomass crops grown on a land area that is 2.8% of the timberland area could produce 22% of the total biomass

80 km radius and road network around Lyonsdale, NY (Castellano and Volk 2008).
Willow Biomass Crops

- Over 350 species of willow in the world
- Shrub willows are the main focus (>175 species)
- Pioneer species adapted to marginal conditions
- Coppicing ability
  - One planting, up to seven harvests
- Rapid growth and canopy closure
- Yields of fertilized and irrigated unimproved clones have reached 27 odt ha\(^{-1}\) yr\(^{-1}\) (Adegbidi et al. 2003)

Three year old willow biomass crops.
Willow Biomass Production Cycle

- Site Preparation
- Planting
- Coppice
- First year growth
- Harvesting
- Early spring after coppicing
- One-year old after coppice
- Three-year old after coppice
Economics of Willow – Base Case

- Improve economics by increasing yield, optimizing harvesting systems, and improving crop management, and producing multiple products from each ton of biomass

NPV: ~ $116/ha  IRR: 5.5%  

(Buchholz and Volk, in press)
Willow Production Cost Structure

- Stock removal: $740 ha\(^{-1}\)
- Transport: $1,179 ha\(^{-1}\)
- Harvest: $3,778 ha\(^{-1}\)
- Fertilizer: $1,225 ha\(^{-1}\)
- Establishment: $2,709 ha\(^{-1}\)
- Administration: $276 ha\(^{-1}\)
- Land cost and insurance: $1,955 ha\(^{-1}\)

(Buchholz and Volk, in press)
SRWC Harvester Development

- Harvesting is the single largest cost of producing willow biomass crops
- Dormant season, single pass cut and chip harvesting system based on New Holland (NH) forage harvester
- Trials since 2005 with Case New Holland forage harvester and specially designed cutting head
- Latest trials in willow and hybrid poplar indicate that this system is effective and can harvest stems up to 15 cm in diameter

New CNH Short-Rotation Coppice header being tested in western NY in early 2009
Moving Chips to the Edge of the Field

Self-unloading forage wagons

Forage blower

Covered over-the-road trailers (30-36 tons of chips)
Moving Chips to the Edge of the Field

Forage dump wagon

Open top over-the-road trailer (25-30 tons of chips)

Large forage dump wagon
Effect of Increased Yield

- With a base case yield of 12 odt ha\(^{-1}\) yr\(^{-1}\), internal rate of return is \(\sim 5.5\%\).
- A 50% increase in yield more than doubles the IRR.
- Improve yield through
  - breeding and selection
  - Improved crop management including weed control, matching clones to sites, nutrient management, spacing, rotation length etc.
Increased Yields from Breeding and Selection

New varieties contribute to 21% greater yield

(Tully ‘05 and Belleville ‘05 Cameron et al., unpublished data. Other sites from Kiernan et al. 2003)
• BCAP would increase IRR even on low yielding sites (6 odt ha\(^{-1}\) yr\(^{-1}\))
  – Extensive planting with poor establishment and poor yields will probably stall out the development of SRWC once the incentives are removed
  – This is the pattern that occurred in Sweden in the 1990s
Price for Biomass

- Generating more value from the feedstock should raise the price for the feedstock
- Increasing price can have a dramatic effect on IRR for willow biomass crops

Effect of changes in the price for willow biomass on the crops IRR (Buchholz and Volk 2010)
Incremental Deconstruction of Woody Biomass to Produce Value Added Products

Woody Biomass

Chemical components of wood

- 21% hardwoods
- 25% softwoods

Lignin

- 35% hardwoods
- 25% softwoods

hemicellulose

- 2-8% extractives

- 45% cellulose

(Liu 2008)
ABS Process

Non-food, lignocellulosic feedstock

Hot water extraction

Extracted woody biomass

Combustion as pellets or chips

Pulp

Fiberboard

Bioconversion Feedstock

Water-based extract solution

Multiple Separation Steps

Raw material for

Long-chain sugars

Natural, wood-based chemicals

Separations

Fermentation sugar feedstock

Lignin

Acetic Acid

Methanol

Formic Acid

Furfural

RO Water
SUNY ESF
Hot water extraction vessel
Wood chips after two hours

Extract solution after two hours
Multiple Products from Wood

• After extraction:
  – Darker color
  – Structure still intact
  – Cellulose and lignin maintained
  – Same volume and shape
  – 20-23% lower mass
  – Lower ash content
  – Higher energy content
Multiple Products from Wood

- Higher lignin content gives these pellets greater structural strength with fewer nubs
- Ash content is premium grade even from wood with bark
- Removal of hemicellulose makes wood less likely to reabsorb water
Multiple Products from Wood

Submerge an extraction pellet & a conventional pellet in water

1 minute

15 minutes

Extracted pellet still in tact

60 minutes
Multiple Products from Wood

Then, air dried for 24 hours

Extraction pellet still in tact

Conventional pellet disintegrated
Wood Based Biorefinery

- Evolutionary Change - Wood cost at $60-100 per dry ton ($0.03-0.05/dry pound) and extraction at 20% of mass with 2/3 as sugars and 1/3 as acetic acid/extractives
- Sugars at $0.10/pound and acetic acid/extractives at $0.50/pound
- Produces $92 odt⁻¹ value for the 400 pounds extracted, which is most of the feedstock cost
- Remaining 80% of wood mass can be converted to pellets for heat and power, paper or other solid wood products with some additional beneficial characteristics
- Trials have been completed with various hardwoods and varieties of willow
The Future for SRWC

• SRWC are in their infancy in terms of development and deployment
• Need to improve the economics of SRWC
  – Increase yield through genomics, breeding and selection
  – Optimizing production systems in relation to weed control, nutrient management, density, rotation length
  – Improving harvesting systems to lower these costs
  – Increasing the value of a ton of woody biomass

Distribution of costs for willow biomass crops over five 4-year rotations (Buchholz and Volk 2010)
The Future for SRWC

• Potential for increasing multiple benefits from SRWC systems including biodiversity, soil and water quality
• Integrating SRWC into the landscape will enhance these benefits
• Combine SRWC with other woody biomass sources to provide consistent flow of feedstock
• Need to increase the value of woody biomass by making a wider range of products from each ton
Acknowledgements

- NYS Energy Research and Development Authority (NYSERDA)
- NYS Dept. Agriculture and Markets
  - NYSTAR
  - USDA CSREES
  - US Dept. of Interior
  - US DOE