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Reducing the Cost of Willow Biomass by Improving Willow Harvest System Efficiency and Reducing Harvesting Costs

Executive Summary

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EXECUTIVE SUMMARY

Short rotation woody crops (SRWC) such as shrub willow are projected to be a major part of the supply of biomass feedstock for the production of bioenergy, biofuels and bioproducts in the U.S. over the next 20 years. Despite their wide array of energy security, environmental and rural development benefits, the expansion and rapid deployment of these crops has been restricted by their high cost of production and a lack of acceptance of willow biomass chips in the market place.

One of the key barriers to rapid deployment is an efficient and effective harvesting system. For willow biomass crops harvesting is the largest single cost factor, making up almost 1/3 of the final delivered cost of the biomass. Harvesting, handling, and transportation together account for 45-60% of the delivered cost of willow biomass. Improving harvesting efficiency will reduce the delivered cost of SRWC and will help to overcome one of the perceived barriers with SRWC, which is that they cannot be harvested economically. Harvesting is also the second largest input of primary fossil energy in the system after commercial N fertilizer, accounting for about 1/3 of the input, so improving harvesting efficiency will also increase the environmental benefits associated with this system.

Harvesting systems previously tested in willow biomass crops produced stringers and inconsistent sized chips that caused blockages when the chips were tested in commercial wood chip user operations. These negative experiences created resistance to the use of willow biomass among potential end users. As a result potential willow crop producers have been hesitant to plant willow biomass crops because there was a lack of commitment from end users to buy willow chips and the willow producers were uncertain how willow crops will be harvested. The focus of this NYSERDA project was to continue the development and testing of a single pass willow harvesting system based on a New Holland (NH) forage harvester that would efficiently and economically harvest willow biomass crops and produce a consistent size willow chip.

The first efforts to develop a harvesting system for willow biomass crops in the U.S. were based on a tractor mounted system called the Bender that was developed in Sweden. The Bender was designed to cut and chip willow biomass crops in one pass, but during two years (2002-2003) of testing the model (Bender Mark V) we purchased in 2001, produced an unacceptable number of long stringers and chips of inconsistent size and quality. In addition this model of the Bender was not mechanically robust enough to handle the size of the willow crop in the U.S., and failed numerous times. Further development and testing of the "new" model Bender "Mark V" in the U.S. was discontinued in 2004.

Beginning in 2004 Case New Holland (CNH) started to collaborate with SUNY-ESF to develop a single pass harvesting system for willow biomass crops based on their NH forage harvesters. NYSERDA and USDA CSREES provided support that was essential to initiating this collaboration and the development of this new harvesting system. The initial tests with a modified row independent corn header and a NH FX45 forage harvester (Figure 1ES A) indicated that this forage harvester could effectively and efficiently chip willow biomass crops and produce a consistent size chip. However, the cutting header was not robust enough, so a new header system needed to be created. A much more robust willow cutting header, built by Coppice Resources Limited (CRL) in the United Kingdom, was modified by CNH to be hydraulically driven and fitted to a NH FX45 forage harvester (Figure 1ES B) with support from the US Forest Service. This combination was used in tests starting in the spring of 2006 with support from NYSERDA and USDA CSREES. In 2008 the CRL header was further modified and tested on NH's new series of FR9000 forage harvesters (Figure 1ES C).

Figure 1ES: Development stages of the willow biomass harvesting system over the past few years in cooperation with Case New Holland. A-The FX series New Holland forage harvester with a modified corn head. B-The modified CRL willow cutting head mounted on a FX series New Holland forage harvester. C-The modified CRL willow cutting head mounted on the new FR series New Holland forage harvester. D-The newly designed New Holland short rotation coppice cutting head mounted on the FR series New Holland forage harvester.

While the modified hydraulically driven CRL header was a significant step forward in the SRWC harvester development, testing with both the NH FX and FR series forage harvesters revealed a number of limitations. The harvested willow chips continued to be consistent in size and of high quality, but the cut willow stems did not flow smoothly and consistently from the header into the throat of the forage harvester where they could be grabbed by the harvester feed rollers, fed into the forage harvester and chipped. The CRL header does not have an active cut stem collection system, so once stems are cut, the movement of the stems toward the throat of the forage harvester is driven by the forward motion of the harvester and the rotation of the saw blades on the header. During testing, cut willow stems frequently became jammed in the CRL header and were not fed into the throat of the harvester. When these jams occurred the harvester operator would have to stop and clear the jammed willow material by reversing the direction of the saw blades and/or the feed rollers and then start the feeding process again. In cases where this procedure did not work, the material would have to be cleared away from the CRL header manually. Despite making a series of modifications to the

CRL header and forage harvester, no more than about 0.5 ha (1 acre) of willow was cut at any one time without having to stop to clear jams of cut willow stems. Modifications included adding deflectors on the CRL header and changing the feed rollers in the FX series forage harvester to make them more aggressive. While these changes helped in some situations, they did not consistently correct the problems created by an inconsistent flow of cut willow stems into the harvester. As more testing occurred with different combinations of the forage harvesters and the CRL cutting header in a range of SRWC conditions, it became apparent that serious work to modify the CRL header with some type of active cut stem collection would need to be done to resolve the crop flow problem. This prompted the next stage in the development of this harvesting system: the design and construction of a "new" header dedicated to short rotation woody crops such as shrub willow by CNH. In 2008, CNH developed and built a prototype header designed specifically for short rotation woody crops that would attach to the FR9000 NH series forage harvesters that could cut and chip a variety of different types of SRWC (Figure 1ES D).

The NH 130FB short rotation coppice header attachment for the NH FR9000 series forage harvester uses circular saw blades mounted in a horizontal plane to cut short rotation woody crops (Figure 2ES). These saw blades spin at approximately 2900 rpm. Feeder drums located vertically over the saw blades rotate at approximately 160 rpm to actively collect and feed the crop back into the forage harvester. In addition, the header has three horizontally mounted feed rollers that help feed cut stems back into the FR9000 base unit feed roller module. The lower front feed roller in the header (often referred to as the paddle roll) has deep paddles on it to help flip the base of each stem up into the two feed rollers behind it that are spring loaded. These two rear feed rollers in the header grab the crop and draw it back toward the feed roller module of the FR9000 harvester. This NH FR9000 based harvesting system provides woodchips of a precise and uniform length and size. The size distribution of the chips can be modified to meet the needs of different end users by .making adjustments in the cab. The design of the FR9000 series based harvesting system minimizes the contact of the woody crop with the ground by operating as a single pass cut and chip unit and thereby minimizing the problems of soil contamination.

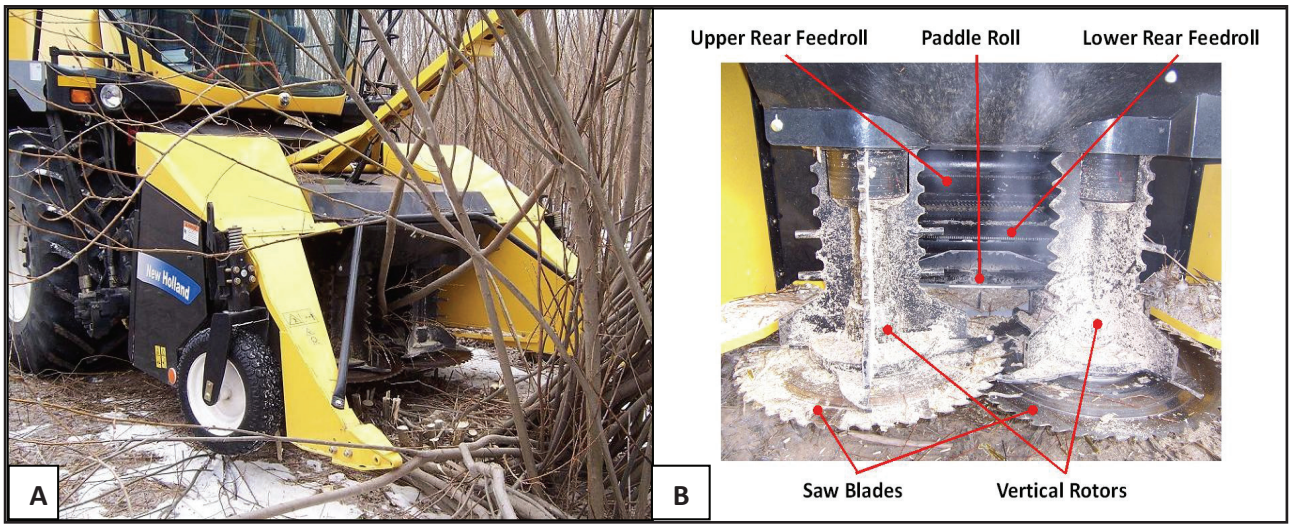

Figure 2ES: NH Prototype header and feeding system. A- NH Prototype 130FB header mounted on FR9060 forage harvester cutting willow in New York State. B- NH Prototype 130FB woody crop cutting and feeding system.

Initial tests with the prototype NH 130FB header in the winter of 2008-2009 indicated that the active collection features of the system had the potential to dramatically improve the flow of stems into the harvester, but also revealed a number of problems with the unit that needed to be addressed. The improvements and modifications made to the unit after the initial testing included strengthening the saw blades and friction plates, shortening the fins on the vertical rollers and making them replaceable, and modifying the guide arm/push bar. Testing in the spring of 2009 indicated that the modifications and upgrades made to the NH 130FB header after the 2008-09 winter tests were extremely successful.

Over the duration of this project, more than 10 hectares (25 acres) of willow biomass crops were harvested (Figure 3ES) with various versions of the harvesting system, and about 650 tons of willow biomass chips were delivered to various heating and combined heat and power (CHP) end users for trials. The size distribution of the willow chips from the harvester were consistent, with almost 80% of the chips being less than 28 mm (11/8 inches) in size, making the chips easy to handle in the systems where it was tested. By the end of this project, willow stems up to 100 mm (4 inches) in diameter were regularly being harvested, which was a major improvement over earlier versions of this system. Using the combination of the NH FR900 series forage harvester and NH 130FB short rotation coppice cutting header, willow biomass crops up to 100 mm (4 inches) in diameter can be cut effectively and reliably with harvesting rates of about 0.6 to 0.7 ha (1.5 – 1.7 acres) per hour. Another limitation with the CRL header was that snow was picked up and blown into the wagons with the chips. This caused end users to be concerned about the amount of water in the loads of chips. The NH 130FB cutting header is designed to address this issue and pick up less snow then the CRL header, but so far has not been tested in the snow.

Figure 3ES: The NH 9060 Forage Harvester mounted with NH FR 130 SRWC header harvesting willow into a forage dump wagon in western NY.

During the course of this project all the different stages of harvester development were displayed and demonstrated at various public events and at field days organized by SUNY ESF and CNH, including a display on the mall in Washington DC as part of the Smithsonian Folk Festival (Figure 4ES) and the Empire Farm Days in upstate NY. As a result of these events and interactions with various farmers and professionals in the agriculture sector, two different methods for handling chips produced in the field by the NH harvesting system were tested. One involved the use of forage dump wagons that can either be unloaded directly into a waiting truck or unloaded into a larger forage dump wagon at the side of the field, which then unloads into waiting trucks (Figure 5ES A). The other system uses self unloading forage wagons to remove the chips from the field and a silage blower to blow the willow chips from the forage wagons into a waiting truck (Figure 5ES B). Due to the experimental nature of the equipment that was run in the various trials during

this project, precise data to compare the efficiency of these two systems could not be collected. Preliminary analysis suggests that the two systems are similar, and in the early stages of the deployment of willow biomass crops, the type of equipment that is available locally will probably influence the type of system that is used.

Figure 4ES: The single pass cut and chip harvesting system based on a New Holland forage harvester and modified CRL cutting head on display on the mall in Washington, DC

The harvesting system for willow biomass crops has undergone a dramatic set of changes and improvements that have increased its efficiency and effectiveness during the duration of the project. As a result, the attitude toward willow biomass crops has begun to change as truckloads of clean and consistently sized chips produced from these trials have been provided to different end users over the past few years. As they become more comfortable with the consistency and quality of the chips produced from this harvesting system, they should be more willing to commit to purchase willow biomass crops from local producers. For landowners to become involved in the production of willow biomass crops they need to have markets for the material and see an effective harvesting system in operation. The development of the harvesting system based on a NH forage harvester under this NYSERDA funded project has been an essential step in addressing these barriers by reducing harvesting costs, producing good quality chips, providing loads large enough for commercial users to test, and providing producers and end users an opportunity to see the system in operation at public events. Over the next two years, with support from the U.S. Department of Energy, SUNY ESF, Case New Holland, Mesa Reduction and Engineering and Greenwood Resources will collaborate to continue to improve the effectiveness, reliability and efficiency of this harvesting.

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