Energy Performance Systems, Inc.

Owner & Developer of the Whole Tree Energy™ Technology

Project Title: Improving the Efficiency of Planting, Tending, and Harvesting Farm-Grown Trees for Energy

Contract Number: RD-50

FINAL REPORT
(Milestone 27)

April 19, 2013

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Congressional District: 3 (Corporate Office; Rogers, MN)
Congressional District: 7 (Farm Location; Graceville, MN)
Congressional District: 6 (Equipment Building Location; Big Lake, MN)

Customers of Xcel Energy provided partial project funding through a grant from the Renewable Development Fund

ACKNOWLEDGEMENTS

This project, which was proposed in 2004 and executed over the past 8 years, was completed with the steadfast work of many organizations and people during varying conditions and some very trying times. As Principal Investigator and President of Energy Performance Systems, Inc., I would like to express my heartfelt thanks to all those involved, including our consultants, accountants, landowners, and equipment fabricators.

I would especially like to thank Lynn Wright of WrightLink Consulting for her dedication and hard work over the last 8 years. Her contribution to this Xcel Energy-EPS project has been outstanding.

Mark Ritter at Xcel Energy has earned my special thanks for his support and many valuable suggestions. Communication with Mark facilitated the successful completion of this Xcel Energy-EPS cost-shared project.

Lastly, I would like to thank the following people for their contributions over the these past 8 years, who were largely responsible for making this project a success:

Ken Ragland	Bill Berguson
Beth Davis	Bernie McMahon
Josh Mack	Tom Levar
Dean Frisch	Dan Buchman
Paul Frisch	Ken Hanley
Dale Marihart	Karen Ostlie
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Signed: ___________________________________

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1. EXECUTIVE SUMMARY

This Xcel Energy cost-shared Energy Performance Systems, Inc. (EPS) project demonstrated that farm-grown hybrid poplar trees are a renewable energy alternative to natural gas. EPS developed the equipment and grew the hybrid poplar tree stock to verify the viability of this integrated renewable fuel supply system. The project met all its technical milestones.

The project's first three research objectives were: (1) mechanizing the planting and "establishment" (work performed from planting to when the growing trees do not need weed control) of hybrid poplar cuttings; (2) demonstrating effective weed control and fertilization in densely spaced hybrid poplar plantings; and (3) establishing the commercial potential of the new EPS high-speed tree harvester. These three objectives are covered in Section 2 of this report. A fourth research objective dealt with data collection and analysis of the performance of EPS-developed equipment, hybrid poplar growth, and total production system costs—the data source for Section 2.

Mechanizing the Planting and Growth of Hybrid Poplars

EPS achieved the objective of highly mechanizing the planting and growth of a hybrid poplar tree farm—termed "hybrid poplar establishment" in the report. (Appendix I contains a glossary of definitions and abbreviations.) EPS built and tested its patented high-speed injection planter capable of planting 6 hybrid poplar cuttings every 1.5 seconds. This demonstrated that planting costs using the injection planter with the proper injection springs can be less than half of those using a hand-planting crew.

The injection planter drives unrooted tree cuttings (slips) into the ground. These cuttings are 10 inches long and 5/16 to 3/4 inches in diameter. The planter testing proved that high-speed injection was effective in planting the tree cuttings, even in unprepared ground. The GPS-guided tractor and planter trigger control showed that trees could be efficiently planted with accurate spacing between rows and within rows, an important factor in cross cultivation and weed control.

Driving (1) 6 hybrid poplar cuttings (slips) (2) into unprepared ground (3) at a velocity of 230 feet per second (4) every 1.5 seconds presented a technical challenge. EPS initiated 2 major design enhancements to improve its injection planter beyond its initial design. First, EPS developed, assembled, and field-tested various spring designs—choosing a gas-driven design. Second, in its laboratory EPS built and tested a prototype "automatic slip feeder" for its 6-row injection planter. This automatic slip feeder eliminates the need for the 6 riders who in the past had to hand-feed the 6 hoppers holding the slips. This not only substantially reduces planting costs but also reduces the human error associated with doing a highly repetitive function.

Reducing Tending Costs in Densely Spaced Hybrid Poplar Plantings

A critical performance measure in using renewable biomass for electricity is "tending costs"—the costs of weed control, fertilization, and pest and disease control in high-density hybrid poplar plantings (spaced 5 feet by 5 feet) compared to wider spacings. EPS's densely spaced 5 feet by 5 feet hybrid poplar plantings, a first for commercial-scale hybrid poplar cuttings, achieved lower tending costs than those with wider spacings. Large sections of the planting site with suitable soil types produced estimated standing yields of 48 green tons per acre or 24 oven dry tons per acre (odt/ac) for hybrid poplar clone NM6 under a 6-year first rotation plan. This resulted in tending costs less than the 12-year first rotation plan, conventional plantations growing at the same average annual incremental yield of 4 odt/ac.

A separate small-clone trial showed that alternative clones should also be considered in addition to NM6. This is especially true if a commercial production site were to be established on the moderately-to-poorly drained silty clay or silty loam soils of western Minnesota. EPS also found that effectiveness in weed control and other tending activities in densely spaced planting depended heavily on having the trees accurately placed both within and between rows.

Establishing the Commercial Potential of the EPS Whole Tree Harvester™

The most significant result of the Xcel Energy-EPS project is the fabrication, testing, and commercial demonstration of the EPS Whole Tree Harvester™ (Figure 1). It was designed to harvest a wide range of tree sizes from approximately 4 inches in diameter up to 30 inches in diameter so that it could be used to harvest trees for fiber and timber markets as well as energy markets. In the first 2 tests at the harvester fabrication site, 13-inch diameter trees established the ability of the harvester to easily cut trees the size normally grown for fiber or timber. Later tests are planned to harvest larger trees similar to those grown in the southeastern United States. The hybrid poplar trees planted for the Xcel Energy-EPS project used a 5 feet by 5 feet spacing and produced trees ranging from 2.5 to 5 inches in diameter during 6 growing seasons.

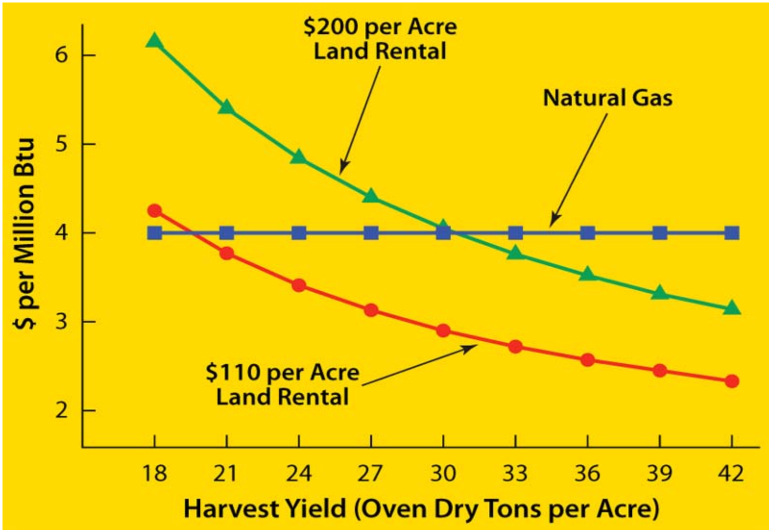
Figure 1: EPS Whole Tree Harvester™

The twin-engine tracked EPS harvester was able to cut and accumulate trees at a rate of 1.6 trees per second while continuously moving forward. This translated to productivity rates of 34 to 174 green tons per acre depending on tree size, and estimated costs of about $4 to as low as $1 per green ton. The lower cost of about $1 per green ton in harvesting 5-inch trees meets the proposed Xcel Energy-EPS project performance objective. The harvester's high productivity rate translates to significantly lower harvesting costs compared to the conventional harvesting systems used today. "Green tons" is a metric that includes the moisture in the trees, which is important in harvesting because trucks must carry this weight. "Dry tons" is a metric that has half the weight of green tons due to lost moisture, its fiber weight being a more relevant measure for the energy and timber industries.

A detailed analysis of project results shows the potential to greatly reduce overall woody crop supply costs—say, of whole trees delivered to a Whole-Tree Energy™ electric generating facility—to about $3.18 per million Btu (MBtu). This is a cost within 25 percent of EPS's original target and competitive with natural gas prices, assuming a harvested yield average of 53 green tons or 26.5 oven dry tons per acre (odt/ac) over 12 years (the average of a 24 odt/ac first harvest and 28.8 odt/ac second harvest) and cropland rental rates of $110 per acre.

Even if a land rental rate as high as $200 per acre is required to assure appropriate site quality and higher crop yields, it appears probable to use the new equipment developed by the Xcel Energy-EPS project to plant, grow, manage, harvest, and transport hybrid poplar trees at a cost per MBtu that is competitive with the cost of delivered natural gas (Appendix A). Figure 2 shows that whole tree wood fuel has a cost advantage over natural gas at 20 dry tons per acre for land rented at $110 per acre or 32 dry tons per acre for land rented at $200 per acre. This assumes that fuel supply overhead costs (for supervision, insurance, and so on) are included in the capital and operating expense budgets of the Whole Tree Energy (WTE™) electric power generating facility (Appendix B), which could utilize the wood most efficiently.

Figure 2: Delivered Cost of Whole-Tree Wood Fuel



NOTE: Green wood is about 50 percent water, so 60 green tons would equal 30 oven dry tons (odt).

Section 5 of this report contains EPS's vision for commercializing the results of the Xcel Energy-EPS project. EPS believes three immediate commercialization opportunities exist:

- **Opportunities for efficiently mechanizing hybrid poplar plantings using the EPS injection planter**. The project demonstrated that the EPS injection planter, using a GPS guidance system, could reduce the cost of planting hybrid poplar cuttings to less than 50 percent of that of hand planting. EPS's improved spring design for its injection planter and its new, innovative automatic slip feeder will further lower the cost of planting hybrid poplar cuttings. This makes the injection planting of high-density tree crops (1,740 trees per acre) an even more cost-effective approach for quickly producing woody crop feed stocks for wood energy production in Minnesota and beyond.

- **Opportunities in weed control and fertilization in the densely spaced tree plantings**. EPS gained and documented hybrid poplar yields as a function of soil types and dense plantings. EPS's high-density (5 foot by 5 foot) plantings allow the wood crop to approach or reach its maximum mean annual growth increment within 5 to 6 years. This establishes the feasibility of growing wood as a feedstock for energy.

- **Opportunities for harvesting trees with EPS's high-speed Whole Tree Harvester™**. The EPS harvester (WTH™) demonstrated the capability of producing clean, uniform, renewable, and low-cost wood for fiber and timber, as well for energy. The WTH™ harvester can be modified in commercial operations to harvest wood for energy, fiber, or timber industries.

EPS made public presentations in 2010, 2011, and 2012 about its planting and harvesting technologies. In early 2013, EPS had a conference call with businesses in the U.S., Chile, Canada, and Poland, all of which were interested in using its harvester for use in their energy and fiber industries. This reinforces EPS's belief that marketable opportunities for its technologies exist. Contacts with potential users and buyers of the technologies are continuing.

2. TECHNICAL PROGRESS IN MEETING PROJECT OBJECTIVES

This Xcel Energy-EPS project addressed technical aspects of achieving a cost-competitive fuel supply for a wood-burning facility by developing and testing new technology and techniques. This section summarizes the technical results of the project, broken down by the original project objectives: (1) mechanizing the planting and growth of hybrid poplars; (2) demonstrating effective weed control and fertilization in densely spaced tree plantings; and (3) establishing the commercial potential of a high-speed tree harvester.

Mechanizing the Planting of Hybrid Poplars

During the project, a 30-foot wide GPS-guided planter was modified after initial tests and then planted approximately 20 acres of hybrid poplars. [NOTE: Details are provided in several project milestone reports—MS 2, MS 4, MS 5, MS 11, and MS 12—and at http://www.xcelenergy.com/Environment/Renewable_Energy/Renewable_Energy_Grants.] Figures 3 and 4 below show EPS's injection planter during the field demonstration. An experienced hand-planting crew planted the remainder of the 80-acre field, which provided information to compare mechanized and hand-planting results.

Figure 3: EPS Planter During Operational Testing Near Graceville, MN

Figure 4: EPS Injection Planter with GPS Guidance System on Tractor 3-Point Hitch

Results of Using the EPS Injection Planter

Planting 20 acres of hybrid poplars with the EPS injection planter demonstrated that the hydraulic injection technology and trigger system works. The trigger system allows energy to be stored in the spring system until the GPS trigger signal fires all 6 rows at the same time. Operation of the 30-foot wide planter with 6 hydraulic injectors showed that 6 rows can be planted simultaneously and result in an accurate spacing distance between trees in the row and between rows, thus giving rows 5 feet apart and trees 5 feet apart within a row.

Tightly spaced plantings require accurate spacing distances to use other machines later for weed control or fertilization without damage to or destruction of misplanted, out-of-place trees. The mechanized EPS injection planter did not damage the poplar cuttings planted during injection (when they met the minimum specified size of 5/16 inch diameter) and they sprouted and grew with similar survival and growth rates as those in the hand-planted area of the field.

When the EPS injection planter was operating without rubber spring failure, the fast planting rate and the GPS guidance system eliminated the need for pre-marking, so costs were less than the hand-planting crew costs of 7 cents per cutting. EPS addressed the rubber spring problem later by testing gas springs instead of the rubber ones. While the newly designed gas springs were only tested under laboratory conditions, EPS calculations suggest they will provide the energy storage and speed required to reach the original technical objectives.

For example, assume that (1) the speed of 6 tree cuttings planted every 1.5 seconds or less (at the design injector velocity of 230 feet per second) can be reached with the redesigned springs and (2) daily10-hour shifts have 8 hours of continuous operation per day of the injection planter for 2 months each year. This shows that average commercial planting costs per cutting can be reduced from about 7 to 5 cents per cutting to about 3 to 2 cents per cutting in the first year of operation, and further reduced after initial investment to as low as 1 cent per cutting.

Automating the EPS injection Planter

The operational field tests of the EPS 6-row injection planter used 6 riders to fill the 6 hoppers containing the tree cuttings. Seeking ways to both reduce planting costs and reduce the possibility of human error, EPS designed a prototype to automate the planting of the tree slips. EPS built and successfully tested its "automatic slip feeder" in its mechanical laboratory.

EPS's automatic slip feeder will replace the 6 riders that feed the hoppers on the injection planter with a single person who feeds the 6 automatic slip feeders as the planter proceeds along the field. The central feature of the automatic slip planter is a circular steel drum that is 5 feet in diameter and 12 inches deep that holds and feeds the unrooted cuttings to the injectors. The automatic slip feeder can readily be integrated into the EPS injection planter and is powered by the existing EPS tractor.

Results of Using Hand Planting

Areas of the field that were hand-planted for the project did not achieve an accurate spacing distance between trees. This occurred even though the planting locations had been pre-marked to establish the desired checked pattern.

EPS estimates the hand-planting costs to have been 6 cents per cutting in 2006 and 7 cents per cutting in 2007, including the cost of pre-marking the field. The range of commercial plantings costs of 5 to 7 cents per cutting was used as the benchmark for reducing planting costs. This is because the EPS hybrid poplar production cost comparisons discussed later in this report cite a publication (Berguson, et al. 2010), which shows planting costs at 5 cents per cutting. Costs of pre-marking the field are included as a separate cost that could be easily overlooked.

The only situation where pre-marking may not be needed prior to hand planting (for establishment of hybrid poplars) is where fields are irrigated and planters would plant the cuttings next to drip nozzles laid out in advance of planting. Hand planting costs are likely to grow, given the increasing difficulties of bringing experienced crews of workers into the U.S. So, EPS believes that its injection planter will more than meet the goal of reducing costs by 50 percent in 2013 and beyond if the re-designed EPS injection planter were to be used for commercial planting.

Weed Control, Fertilization, and Biomass Growth of Densely Spaced Plantings

This section discusses the 5 hybrid poplar sites in the study. Four sites measured annual and cumulative growth of hybrid poplar NM6 and weed control and fertilization on the sites. The fifth site reports on a clone comparison experimental trial.

The Five EPS Hybrid Poplar Tree Sites

EPS organized plantings of hybrid poplar cuttings in 2006, 2007, and 2008. The 2006 and 2007 commercial scale plantings were both established on approximately 80 acres of land and in 2 very different areas of Minnesota: 1 in the south central region of the state (Glencoe) and the other in the western region (Graceville). As discussed below, the Graceville plantings were on 2 separate 40-acre sites. Machine planting was conducted on the Graceville West site, and it will be treated separately from the Graceville East site.

In 2008, the project added small plantings of hybrid poplars at 2 separate locations in western Minnesota near the town of Dumont. A 10-acre site focused on evaluation and growth of the clone NM6 and is referred to as a "Production Evaluation site." The 5-acre site was planted with 10 different hybrid poplar clones including "standards" NM6 and DN34, 4 less commonly planted commercial clones, and 4 new clones. This site is called the "Clone Comparison site. "

The Glencoe Site. The first planting in south central Minnesota (Glencoe) in 2006 provided an opportunity to document establishment success, tending requirements, and growth results of hybrid poplar clone NM6. Due to several factors, the project lost access to the site after the first growing season. However, much was learned from the 1-year field trial. EPS collected data on establishment results achieved by a commercial hand planting crew and growth results for the year.

The Graceville West Site. EPS established the second planting in 2 fields of about 40 acres each in western Minnesota (Graceville) in 2007 in cooperation with the farmers who greatly assisted the project. However, the quality of the land on both fields was quite variable, with soil types ranging from moderately well drained to very poorly drained. About 25 percent of the west site contained moderately drained soil areas that fully met the requirements of the NM6 clone (with spot yield estimates of nearly 6 odt/ac/yr)—termed "Graceville West." EPS used the Graceville West site as the research location for testing its injection planter and EPS Whole Tree Harvester™ under operational conditions. The team collected growth and survival measurements over a 6-year period from both hand and machine planted sections of the field.

The Graceville East Site. The 40 acres of the Graceville East site also contained a similar range of good to poor soil types. All cuttings were hand-planted. This site will be termed "Graceville East" and growth results will be reported separately. The variability of the Graceville fields provided good research conditions for re-evaluating hybrid poplar soil requirement recommendations over a 6-year period.

The Dumont Production Evaluation Site: Clone NM6. The 2008 planting was on a 10-acre location in western Minnesota (Dumont). It was expected to provide information on the growth of hybrid poplar clone NM6 on a good quality soil type, and 15 measurement plots were set up within the site. However, the landowner was not aware of all previous uses of the land.

One corner of the 10 acres produced extreme weed populations and tree mortality normally associated with a heavy concentration of dairy cattle manure. Also, the Dumont site bordered land that was in the Conservation Reserve Program of the U.S. Department of Agriculture. EPS collected growth and survival measurements over a 5-year period. This site was planted by an EPS contractor using a 1-row furrowing tree planter of the type commonly used for small forestry plantings.

The Dumont Clone Comparison Site: 10 Clones. EPS also added a fifth planting site to the project in 2008 to evaluate 10 clones other than NM6. These 10 clones were provided and planted by Iowa State University (ISU) across a 5-acre site at Dumont that included upland, mid-slope, and low-lying portions of a field. Most of the field (75 percent) shows on soil classification maps as poorly drained, silty clay soils. EPS believed this to be an excellent site for testing the response of different clones to different site conditions. The shape of the site was not ideal, meaning that not all clones could be placed in all sections of the field. Also, the results from the trial cannot be fully extrapolated to commercial conditions since all clones were planted with 1-year old rooted cuttings at very high cost rather than as commercial, lower-cost unrooted cuttings. These rooted cuttings were planted in pre-dug holes approximately 8 inches in diameter and 18 inches deep.

Planting, Tending, and First-Year Survival Rates of the Hybrid Poplars

The Glencoe site, both Graceville sites, and the Dumont Production Evaluation and Clone Comparison sites were used to test planting and tending methods as well as first-year survival. Plantation tending included monitoring the sites for diseases and damage from deer and insects, as well as managing the weed competition and necessary fertilization.

Planting, Tending, Herbicides, and Fertilizers. Weed competition, especially from grass, was a concern. EPS made efforts at all of the sites to follow standard hybrid poplar establishment procedures, using pre-planting herbicides during site preparation and post-planting herbicides after planting. Where successfully applied, herbicides were effective for about 6 weeks. Rains immediately after planting eliminated that plan at both Dumont sites. Portions of the Graceville fields also did not receive the intended chemical treatment due to lingering rains before and after planting and competition with spray equipment needs for grain crops.

Getting commercial herbicide equipment into the plantings after the first year was not possible with the 5 feet by 5 feet spacing of cuttings. But EPS found that a brush cutter attached to an all-terrain vehicle (both about 4 feet wide) was suitable for keeping weed heights reduced in between the rows (Figure 5). It would have also been possible to mow across the rows if a fully functioning GPS-guided machine planter had been used to plant the whole field.

Figure 5: Mowing Equipment for 5 × 5 Spacing

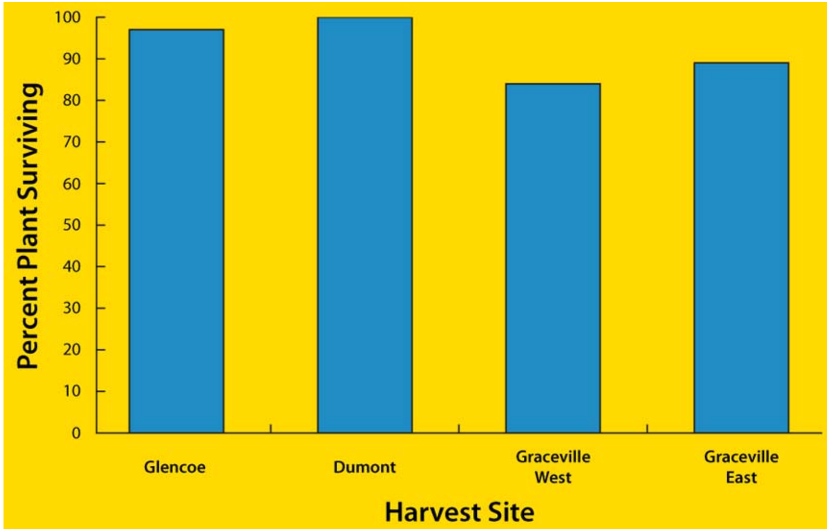
EPS planned for site fertilization to occur by the third growth year as part of the establishment and tending objective only if needed. EPS judged in the spring of the third year after planting that growth appeared excellent in the good sections of the sites. In the poorer sections of the sites, EPS felt that fertilization would encourage weed growth more than tree growth.

A small fertilizer trial was run on the Graceville West field in the spring of the fourth year after planting. EPS selected a 1-acre, T-shaped area so that it included 3 annually-measured plots with both good and poor growth areas. The fertilizer used was Osmocote Pro 22-3-8 NPK plus magnesium, sulfur, copper, iron, manganese, and zinc. The amount applied over the entire acre was 140 pounds, equivalent to 31 pounds of elemental nitrogen per acre.

EPS identified no growth response to the fertilizer application in the experiment's fourth, fifth, or sixth year. Details of site preparation, planting, and tending activities for all sites plus preliminary results for hybrid poplar survival and growth are described in Milestone reports 6, 8, 12, 14, 16, 18, 20, 23, and 25. See http://www.xcelenergy.com/Environment/Renewable_Energy/Renewable_Energy_Grants.

First-Year Survival Rates of NM6 Cuttings. First-year survival evaluations of NM6 cuttings (taken in 15 plots on the Dumont site and in over 30 plots at the other sites) showed very good survival rates at all 4 NM6 production sites. As shown in Figure 6, these ranged from a low of 83 percent at the Graceville West site to a 100 percent survival at the Dumont site. The lower survival rates at the Graceville West and East sites was probably due to poor growth in very poorly drained spots in the field and grass competition in some areas.

Figure 6: Percent of Planted Trees Surviving at End of the First Growth Season

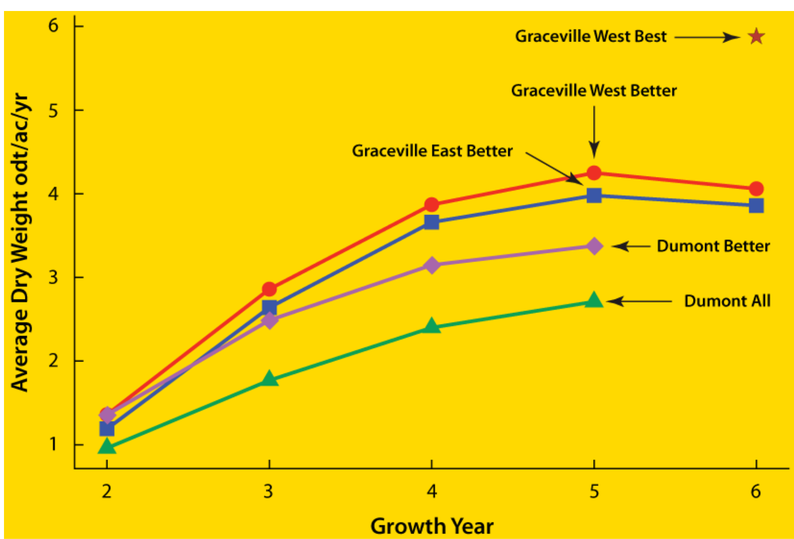


Biomass Growth for the Hybrid Poplars

Five plots were measured annually in the in the 25 percent of the Graceville West field that was considered to be suitable for hybrid poplar growth. These measurements provided information on the growth patterns of the trees for the NM6 clone for (1) the annual incremental biomass growth and (2) the cumulative biomass growth.

Annual Incremental Biomass Growth. Figure 7 shows that the maximum mean annual increment (MAI_{max}) of biomass growth of the NM6 clone was slightly higher than 4 odt/ac/yr and was reached by the fifth year. It also shows that the best plot in the Graceville West site produced a MAI_{max} for NM6 of about 6 odt/ac/yr by age 6.

Figure 7: Mean Annual Incremental (MAI) Biomass Growth of NM6



Cumulative Biomass Growth. Figure 8 shows that a total standing biomass of about 24 dry tons at harvest using the NM6 clone was achieved late in the growing season of the sixth year for the better Graceville West and East sites. The initial growth rate in the first year on the Dumont Production site was excellent, exceeding that on other sites. But by the fifth year, the Dumont biomass growth rate was less than that observed on the Graceville fields. However, Figure 8 shows that the best measurement plot in the Graceville West area of NM6 hybrid poplars exceeded 35 oven dry tons per acre (odt/ac).

Figure 8: Cumulative Biomass Growth of NM6

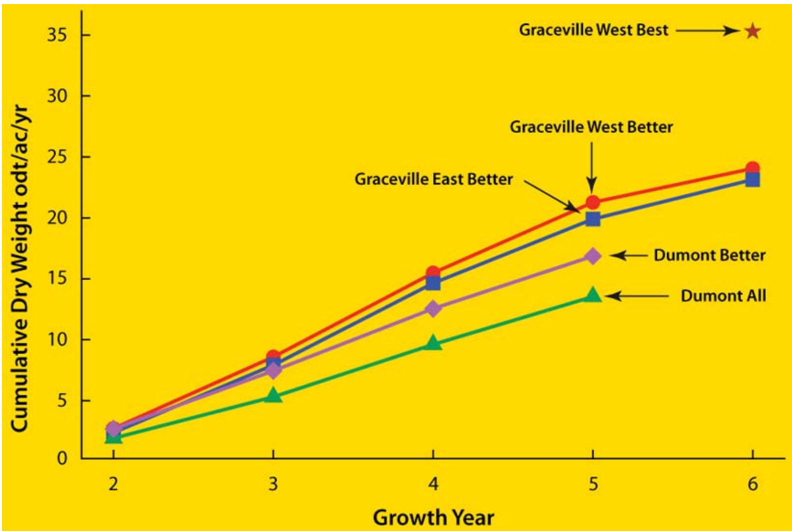
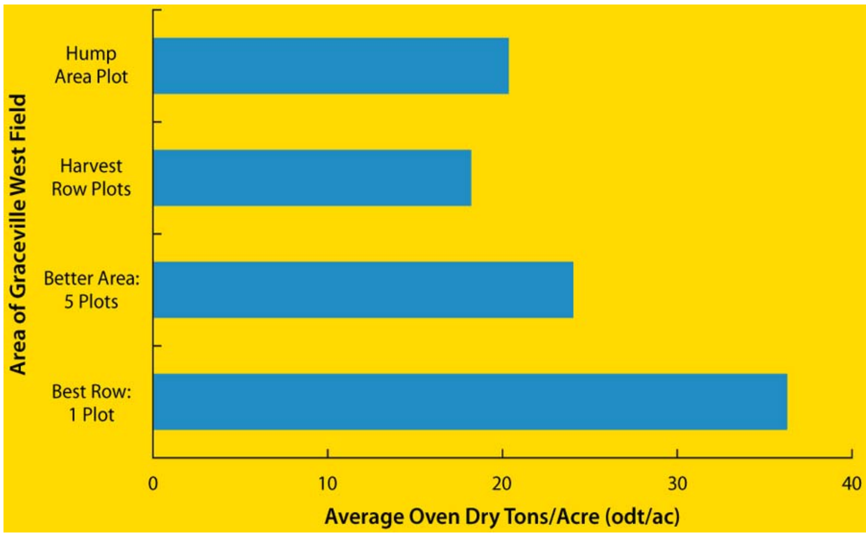


Figure 9 shows a high density Graceville plot in the sixth growth year, where higher yields were expected. Marssonina leaf disease occurred in 2011 at a level never before seen according to Bill Berguson, a hybrid poplar researcher at the University of Minnesota. The disease's effects were widespread across Minnesota, attacking even 50-year old trees and the 20,000 acres of Verso Paper plantings. This very likely caused the reduction in growth rate in 2011 and 2012 of all hybrid poplar plantings in the Xcel Energy-EPS project.

Figure 9: A Graceville Plot Producing Estimated Harvest Yield of about 24 odt/ac

In the project's final year, EPS measured the standing cumulative growth in additional areas of the Graceville West field to evaluate how well the annually measured plots represented the approximately 20 acres that had soils suitable for producing hybrid poplar trees from the NM6 clone. Figure 10 shows that plots in average areas of the Graceville West field produced about 20 oven dry tons per acre (odt/ac), 5 plots in the better area of Graceville West produced about 24 odt/ac, while the best single row produced about 35 odt/ac.

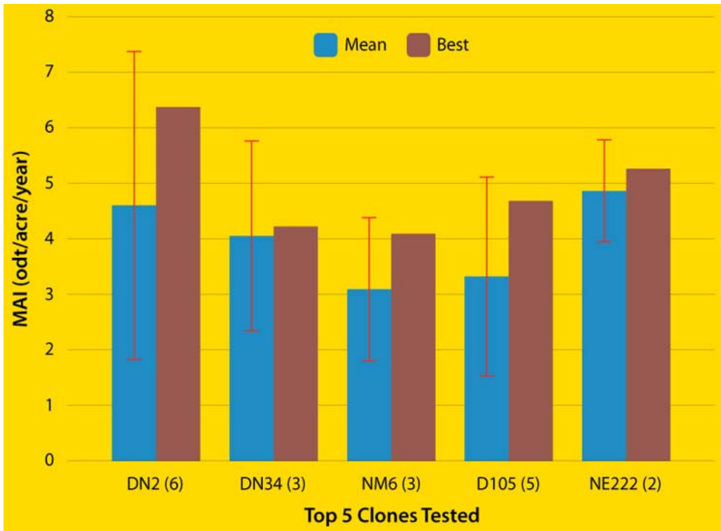
Figure 10: Comparison of 6-Year Cumulative NM6 Growth in Various Areas of the Graceville West Field



On 5 acres at the Dumont site, Iowa State University (ISU) researchers planted 10 clones as rooted 1-year old cuttings following normal protocols for clone comparison trials planted in remote locations (Appendix F). The growth advantage of the rooted cuttings was reduced in our estimates of mean annual growth increment (MAI) by dividing the total biomass by 6 years instead of by the 5 years they actually grew in the field. A combination of heavy deer browse, failure of the new noncommercial clones provided by ISU to survive, and flooding conditions on a part of the field the first year after planting made it difficult to evaluate the results. With this potential limitation, the trial did suggest that clonal variations could make an important difference in tree growth.

Only 5 of the 10 clones planted survived well enough to be included in the EPS assessments shown in Figure 11. The numbers in parenthesis below the clone identification number are the number of plots in the trial. The best growth performance in a single plot was obtained by hybrid poplar clone DN2 and estimated to represent a 6-year growth rate of about 6.2 odt/ac/year (assuming 100 percent survival). Due to high variation among 6 plots, the mean growth of DN2 across all plots was not very different than that of the 4 other clones shown in Figure 11. While the growth of clones DN2, DN34, D105, and NE222 appear to be similar to or better than NM6, the results are based on planting rooted cuttings and are likely to be relevant only to the poorly drained, silty clay soils and climate conditions existing in western Minnesota.

Figure 11: Mean Annual Increment (MAI) Growth of Top Five Clones (10 clones tested)



Clone DN2 (Figure 12) has performed relatively well in other parts of Minnesota on poorly drained silty clay or silty loam soils similar to the clone trial site (Appendix C).

Figure 12: Lynn Wright Measuring a DN2 Clone in the 2008 Clone Trial

The 3 clones DN2, NE222, and DN34 might provide good growth results in future plantings on the heavy, silty clay soils near Graceville and Dumont, Minnesota—assuming they will perform as well when planted as unrooted cuttings. While there were only 2 plots of clone NE222, EPS's 2 estimates of yield showed relatively little variance. This was because 1 plot was in the best area of the field, and the second plot, in a poor area of the field, had only 6 of the 9 measurement trees surviving. But 3 of the 6 surviving trees had very large tree diameters—4.3- to 5-inch diameters at breast height (dbh). Another clone—D105—is known to root poorly when planted as an unrooted cutting, and the high cost of planting rooted cuttings makes it unsuitable for commercial planting. In contrast, clone NM6 has excellent rooting qualities—planted as unrooted cuttings—which makes it a common choice for commercial planting.

Financial Performance of the EPS Hybrid Poplar Plantings

EPS met its performance metric of achieving tending costs—weed control and fertilization expenses—using its high-density (5 foot by 5 foot) hybrid poplar plantings rather than conventional low-density (10 foot by 10 foot) plantings. While the cost of planting 1,740 tree cuttings on 5 foot by 5 foot spacing is obviously much higher than 450 tree cuttings on a 10 foot by 10 foot spacing, the average tending costs EPS experienced at all locations were lower than those experienced for standard commercial poplar tending.

The financial performance of the EPS hybrid poplar plantings divides into cash flow analyses of (1) the hybrid poplar tending costs and (2) the wood delivered at the utility gate.

Cash Flow Analysis of Hybrid Poplar Tending Costs. The EPS hybrid poplar tending costs for 3 different planting scenarios appear in Figure 13 below:

- Scenario 1: Assumes hybrid poplars planted with a 5 foot by 5 foot density are harvested at the end of a 6-year growing period. Tending costs are based on EPS estimates.
- Scenario 2: Is the same as above, except 2 harvests are assumed over a 12-year growing period and the second harvest is made possible by poplar coppicing after the first harvest.
- Scenario 3: Assumes 1 harvest at the end of a 12-year growing period. The tending costs are based on Natural Resources Research Institute (NRRI) estimates.

Figure 13 shows the net present value (NPV) of establishment and management costs, excluding land rent, for the 3 scenarios. The Scenario 1 NPV must be doubled for accurate comparison with Scenario 2 and Scenario 3 because it only involves a 6-year cycle. Scenario 1 is included to exemplify the value of producing harvestable yields in 6 years. So the lowest NPV over a 12-year period is for Scenario 2—where EPS obtains 2 harvests of poplars with a 5 foot by 5 foot density.

An advantage of both Scenario 1 and Scenario 2 over Scenario 3—the NRRI model with 1 harvest of 12-year poplar growth—is in avoiding the extra tillage, herbicide, and weed control costs associated with the lower density of cuttings in Scenario 3 and the 12 years it takes to obtain 1 harvest of wood. Scenario 2 shows more wood grown in its longer 12-year cycle than Scenario 3. Scenario 1 also includes the ability to harvest twice with a single planting because of coppicing.

Scenario 3 from the NRRI model shows a similar NPV of costs to Scenario 2. This similarity appears strange because the number of cuttings planted per acre is less than one third the number used in the other 2 scenarios. This should result in much lower costs for Scenario 3 but significantly increased costs of weed control, including herbicides, which more than offsets the benefit of fewer cuttings per acre.

Figure 13: Cash Flow Summary of Hybrid Poplar Production Inputs[1, 2]

Cost Type per Acre	Scenario 1	Scenario 2	Scenario 3
	One Harvest, 6-year EPS Costs 5 × 5 feet	Two Harvests, No Replant, 12-year EPS Costs 5 × 5 feet	One Harvest, 12-year EPS Costs 10 × 10 feet
Burn-Down Herbicide	NA	NA	$14
Primary Tillage (chisel plowing)	$10	$10	$14
Secondary Tillage Disking	$9 (1 ×)	$9 (1 ×)	$34 (3 × 11.40 each)
Marking	NA	NA	$15
Cuttings	$174 (1,740/ac @ $0.10)	$174 (1,740/ac @ $0.10)	$45 (450/ac @ $0.10)
Planting	$52 (1,740/ac @ $0.03)	$52 (1,740/ac @ $0.03)	$22 (450/ac @ $0.05)
Pre-Emergent Herbicide	$40	$40	$86 $43 each – 2 yrs
Post-Plant Weed Control (cultivation and/or mowing)	$28	$28	$46 $9.30 each – 5 times
Post-Emergence Herbicide	NA	NA	$129 $43 each – 3 yrs
Shield or Spot Spray Herbicides	NA	NA	Not given
Fertilizer	$82 $41 each 2 applications	$246 $41 each 6 applications	$115 $38.20 each 3 applications
Net Present Value (NPV) of all costs (without land rent) at 4% discount rate	$357 6-year cost for producing 24 dry tons per acre; 1 harvest in 6 years	$440 12-year cost for producing 50 dry tons per acre; 2 harvests in 12 years	$451 12-year cost for producing 48 dry tons per acre; 1 harvest in 12 years

[1] Cash flow model from Bill Berguson of University of Minnesota—Natural Resources Research Institute (UM – NRRI). Developed in collaboration with fiber industry; land rent is not included so that input costs can be compared with inputs costs required for alternative crops.
[2] Custom rates are used for tillage and weed control operations; overhead, insurance, and land manager costs area assumed to be capitalized by the Wood to Energy facility, and thus are not included here.

Fertilizer application and pest control costs not incurred by the EPS plantings were added to the cost analysis because they may very well be required under some conditions. Factors contributing to the lower tending costs for the EPS high-density plantings include less site preparation and weed control activity than often recommended. These result from establishing a higher density tree crop. The lower amount of weed control likely interacted with the poor soil conditions to reduce growth in some sections of a field. Yet it verified EPS's expected results that in the better sections of a field, the rapid growth of the tightly spaced trees forced out the weed competition very quickly. Growth in the better-quality plots met or the exceeded growth observed for NM6 in other areas of Minnesota and demonstrated that tending costs can truly be lower in higher density plantings.

Other factors contributing to high yields of many hybrid poplar clones are: (1) pH levels between 5.5 to 7.5; (2) good available water capacity; (3) soil that is less than 40 percent clay; (4) more than 3 percent organic matter; and (5) very limited or no flooding in the spring. So, the preferred sites for growing hybrid poplars contain soils commonly used for crop production that is renting for more than $200 per acre. Therefore, one solution to attaining high yields is to pay higher prices for land for woody crops production. Higher quality land is generally shown to reduce costs not only by supporting higher yields but also by reducing crop management costs.

Cash Flow Analysis of Wood Delivered at Utility Gate. Figure 14 shows the 4 scenarios under which EPS estimated the delivered pieces of the wood per dry ton and MBtu at the utility gate. The first 2 scenarios have similar hybrid poplar growth models as in Figure 13. Harvesting is done by the EPS Whole Tree Harvester™, with the costs being based on EPS assumptions. Scenario 3 uses harvesting costs and hauling costs based on NRRI assumptions of chipping the wood. So Scenario 3 does not involve using the EPS harvester, which results in higher costs for harvesting, producing, and hauling wood chips versus whole trees. Scenario 4 is the same as Scenario 3, except harvesting costs drop from $25 per ton to $3 per ton due to the use of the EPS Whole Tree Harvester™.

Based on these scenarios, Figure 14 shows that 2 harvests of whole trees over a 12-year growing period result in a delivered price per MBtu of $3.18 (EPS assumptions) compared to a $5.12 delivered price per MBtu for a single harvest of wood chips over the same 12-year growing period (NRRI assumptions). A single harvest of whole trees over a 6-year growing period using the EPS harvester yields a delivered price per MBtu of $3.79. The higher delivered price of Scenario 3 compared to Scenario 2 reflects the fact that with a 12-year growing period, the second harvest yields roughly 20 percent more dry tons per acre than the first 6-year harvest. This brings down the average delivered price to $3.18 per MBtu for Scenario 2. Comparing Scenarios 3 and 4, the analysis shows that the delivered price of a single 12-year harvest of wood chips under NRRI assumptions drops from $5.12 per MBtu to $3.86 per MBtu if the EPS harvester is used, since harvesting costs are expected to drop from $25 per ton to only $3 per ton.

The delivered prices for farm-based energy wood in Figure 14 do not include the supervision and management costs that are often added to stand-alone wood supplies. In the case of an electric power generating plant, there are fuel supply overheads normally included in both the capital and operating expense portions of electricity production. Since EPS has developed several farm-based fuel supply plans for power production facilities (approved by large multi-national organizations), it has benefited from this experience and has used this knowledge in the economic analyses.

Figure 14: Total Cash Flow Analysis of Delivered Price for Wood at Utility Gate[3] ($/Dry Ton and $/MBtu)

Source of Cost or Price	Scenario 1	Scenario 2	Scenario 3	Scenario 4
	One Harvest, 6-year, EPS Basis 5 × 5 feet EPS Harvester	Two Coppice Harvest, 12-year, EPS Basis 5 × 5 feet EPS Harvester	One Harvest, 12-year, NRRI Basis 10 × 10 feet Chipped	One Harvest, 12-year, NRRI Basis 10 × 10 feet EPS Harvester
Land Rent per acre per year	$110	$110	$110[4]	$110[4]
Discount rate (4% per year for inflation)	$0.04	$0.04	$0.04	$0.04
Harvest Yield per Rotation (dry tons/acre)	24	24 + 28.8	48	48
MAI (dry tons/ac/yr)	4.0	4.4	4.0	4.0
NPV all costs (with land rent)	$911	$1,433	$1,549	$1,549
Farmgate Discounted Break-Even Cost per Ton (with land rent)	$51	$40	$54	$54
Harvesting Cost per ton[5]	$8	$8	$25	$3
Farmgate Price per ton	$59	$ 48	$79	$57
Haul Cost for 37 mile Average Haul[6]	$7	$7	$10	$10
Delivered Price ($ per dry ton)	$66	$55	$89[7]	$67
Delivered Price ($ per MBtu)[8]	$3.79	$3.18	$5.12	$3.86

[3] Cash flow model provided by Bill Berguson of UMN–NRRI and developed in collaboration with fiber industry.
[4] Land rent assumptions were not provided by NRRI, but EPS land rent costs were assumed for comparison purposes.
[5] Harvester costs are significantly lower for larger trees and for whole trees rather than chip production and loading.
[6] EPS haul assumptions are $2.50 per loaded mile, 25 wet tons per haul and 37 mile average haul of whole trees. NRRI haul assumptions are $3.50 per loaded mile, 25 wet tons and 37-mile average haul of wood chips.
[7] Delivered price per dry ton shown here includes land rent but not "overhead" costs embedded in the "opportunity cost" used by Berguson, et al., (2010) to estimate delivered price. EPS assumes those additional overhead costs are covered by the operational costs of the wood to energy facility.
[8] Assumption of 17.4 million Btu (MBtu) per ton of wood.

Generally, these plans include capitalizing the pre-startup fuel supply costs and include the management in the operations and maintenance costs of the facility which would be located in the center of the 50-mile-radius tree farm system. So, the average haul distance is 37 miles. Besides the lower cost of office facilities, fuel unloading and storage, and other infrastructure costs, these plans allow the power plant to be economically loaded as a base load facility similar to coal-fired plant incremental loading systems. Capitalizing a part of the fuel cost allows this to happen. The power plant would essentially be located at the "mine mouth."

Commercial Demonstration of the EPS Whole Tree Harvester™

The section discusses the commercial potential of the EPS Whole Tree Harvester™ by covering: (1) its planned use with its trailer; (2) developing and fabricating the WTH™; (3) the 3 harvesting tests run in the Xcel Energy-EPS project; and (4) harvesting costs and statistics.

Planned Operations of the WTH™ with its Trailer

The EPS high-speed, Whole Tree Harvester™ has been a marvel to several engineers, including those from a large equipment manufacturer. Based on 2012 testing, EPS believes it has proven it to be the fastest and most productive tree harvester known. This high performance comes from its continuous cutting, accumulating, and loading trailers at speeds exceeding 6 miles an hour, all done without the trees touching the ground. While Figure 15 does not show the harvester pulling the trailer, in commercial operations pole trailers, flatbed trailers, or an EPS-designed 50-ton tracked trailer can be used.

Figure 15: Whole Tree Harvester™ Cutting Trees During Demonstration

Not contaminating the wood is very important when it comes to later processing because clean wood greatly reduces saw blade and/or chipper teeth wear, depending on the type of processing for which the wood is used.

Developing and Fabricating the Whole Tree Harvester™

As often occurs with leading-edge prototypes, developing and fabricating the Whole Tree Harvester™ took longer and cost more than anticipated. EPS contracted for the fabrication of the harvester in Big Lake, Minnesota, and delivered it by truck to a farmstead near Graceville, MN using a trucking company capable of hauling oversized loads (Figure 16).

Figure 16: Whole Tree Harvester™ Prepared for Transport

EPS reassembled the harvester on a site provided by a farmer located near the Graceville 80-acre hybrid poplar farm (Figure 17). The harvester was then driven for the first time over gravel roads to the test site. EPS added final attachments there (including the harvesting head) and successfully performed the first test. Details of the first and second tests of the harvester appear in Xcel Energy-EPS project Milestones 17 and 24 on the Xcel Energy website. See http://www.xcelenergy.com/Environment/Renewable_Energy/Renewable_Energy_Grants.

Figure 17: Whole Tree Harvester™ Reassembled Except for the Cutting Blades and Guides

The Three Tests of the Whole Tree Harvester™

EPS conducted 3 tests with the Whole Tree Harvester™ to harvest hybrid poplars, starting simply and expanding the tests to simulate actual commercial operations.

Test #1: Harvesting 20 5-Year-Old Hybrid Poplars. The first test involved cutting 20 5-year-old poplar trees in an outside row of the plantation. The cutting discs cleanly severed the poplars and automatically pulled them into the accumulator section of the harvester as it moved through the row of trees. After the first test was performed, EPS added an additional guide wheel to the front of the harvesting head to reduce the load from that borne by a single wheel. New software modifications enabled better control of the front and rear tracks. These modifications also improved the operation of the accumulator section by aiding the flow of trees up the skidpan

Test #2: Harvesting a Row of Hybrid Poplars. In the second test, the WTH™ cut down an entire row of poplars at a rate of about 1.6 trees per second. The trees were cut cleanly, traveled smoothly up the skidpan, and were dropped off the rear of the harvester. The harvester includes 2 rows of paddles with a vertical separation of 9 feet that move the trees up and back along the skidpan. If the trees are too small—less than 3 inches in diameter at breast height (dbh)—they tend to bend at the top in going past the top set of paddles and then are pushed up in a near-horizontal position. As in the first test, some of those trees fell onto the skidpan rather than moving along the skidpan in an upright position. These trees would normally be considered "slash" and would be left in the field at the landing site.

The harvester is designed for trees larger than 4 inches in dbh. Harvester productivity increases with tree size and planting density, as the standing tonnage then also increases. After performing the second test, EPS modified the rear track assembly to eliminate a horizontal bending force on the rear stub axle, which kept breaking a keeper weld. EPS plans to install a longer stub axle with a bolted keeper to address the problem. Also, shielding was added to the accumulator section to protect the hydraulics, electrical wiring, and fuel lines from slash from the harvested trees and help guide the trees smoothly up the skidpan and off of the back of the harvester.

Test #3: Harvesting a Row of Hybrid Poplars for Outside Observers. EPS performed the third and final harvest test of the Whole Tree Harvester™ to cut down a row of poplars in the presence of an employee from Xcel Energy representing the Renewable Energy Development Fund and others. As in previous tests, the harvester successfully cut the trees cleanly and quickly at a rate of about 1.6 trees per second and lifted them 13 feet off the ground as they traveled up the skidpan and were discharged. Under normal operating conditions, the trees would be loaded onto a trailer pulled by the harvester. As mentioned earlier, these trees—having never touched the ground—would result in fewer abrasives on the trees and a cleaner fuel for the systems involved in conversion to power. It would also reduce wear on saw blades if shipped to a lumber mill. The same would be true for chipping operations.

Costs and Statistics Related to WTH™ Harvesting

The Whole Tree Harvester™ cost calculations show that it would be profitable during the first year of use under reasonable assumptions. When harvesting trees from well-stocked tree stands from 8 inches to 30 inches dbh in size, the cost per dry ton would be about $4 per dry ton ($2 per wet ton) or less. With smaller trees (such as 3.5 inch dbh trees planted for energy at high density), the cost per dry ton to break even would be near $8 per dry ton, which is still much lower than the industry averages. Several tree sizes are used as examples in Figure 18 below.

Figure 18: Whole Tree Harvester™ Cost Analysis Relative to Tree Size

Cost Element	Tree Size (dbh)							
	3.5 (inches)	5 (inches)	8 (inches)			12 (inches)		
Harvest Speed (fps)	8	6	4	6	8	4	6	8
Tree Spacing (ft)	5	5	10	10	10	10	10	10
Cut Rate (trees/sec)	1.6	1.2	0.4	0.6	0.8	0.4	0.6	0.8
Dry wt/tree (lbs)	38	100	250	250	250	750	750	750
lbs/s	60.8	120	100	150	200	300	450	600
Oven Dry Tons Per Hour	109	216	180	270	360	540	810	1080
Oven Dry Tons Per Year	72,843	143,770	119,808	179,712	239,616	359,424	539,136	718,848
Loading Downtime (%)	84%	84%	84%	84%	84%	84%	84%	84%
Power (%)	27%	28%	15%	23%	31%	20%	30%	41%
Fuel Cost @ $3.50/gal	$67,449	$70,610	$38,217	$57,326	$76,435	$50,416	$75,624	$100,832
Operator	$75,000	$75,000	$75,000	$75,000	$75,000	$75,000	$75,000	$75,000
Maintenance Labor & Parts	39,267	40,450	35,033	42,950	50,867	51,700	67,950	84,200
Capital Cost	$370,000	$370,000	$370,000	$370,000	$370,000	$370,000	$370,000	$370,000
Price $/odt	$8.00	$7.50	$7.00	$6.50	$6.00	$5.50	$5.00	$4.50
Annual Rev ($/yr)	$582,746	$1.08M	$838,656	$1.17M	$1.44M	$1.98M	$2.70M	$3.23M
Harvesting Cost ($/Yr)	$551,716	$556,060	$518,251	$545,276	$572,301	$547,116	$588,574	$630,032
Harvesting Cost/odt	$7.6	$3.9	$4.3	$3.0	$2.4	$1.5	$1.1	$0.9
Net Before Taxes (NBT)	$31,030	$522,212	$320,405	$622,852	$865,395	$1.43 mil	$2.11 mil	$2.60 mil

In addition to estimating costs and potential profits, it became clear that the bottleneck for harvesting lies in the offloading of the loaded trailers. The Whole Tree Harvester™ can cut and load a trailer full of trees faster than the time it takes to hook up a new trailer and haul it off. In order to account for this, an efficiency factor of just 16 percent was used in the calculations. Further cost details are shown in Figures 19 and 20 below.

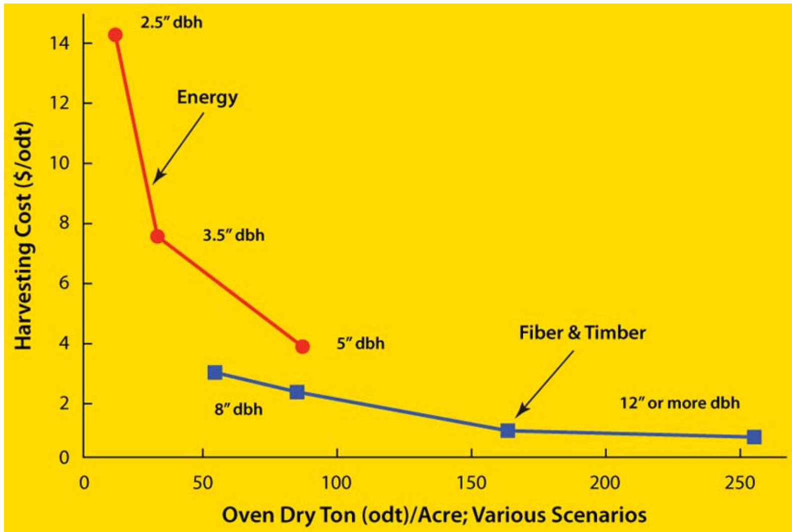
Figure 19: Estimated Harvesting Statistics

Cost Element	Tree Size (dbh)								
	3.5 (inches)	5 (inches)	8 (inches)			12 (inches)			24 (inches)
Harvest Speed (fps)	8	8	4	6	8	4	6	8	6
Green Tree Weight (lbs)	75	127	450	450	450	1,263	1,263	1,263	5,726
Spacing (ft)	5	5	10	10	10	10	10	10	20
Cut Rate (trees/sec)	1.6	1.6	0.4	0.6	0.80	0.40	0.60	0.80	0.30
Green tons per hour	215	367	324	486	648	909	1,364	1,819	3,092
ODT per hour	108	183	162	243	324	455	682	909	1,546
Trees per hour	5,760	5,760	1,440	2,160	2,880	1,440	2,160	2,880	1,080
Height (ft)	29	44	51	51	75	86	86	86	97
Peak Cutting Force (lbs)	428	873	2,234	2,234	2,234	5,026	5,026	5,026	20,102
Travel & Cut Avg Force (lbs)	9,467	9,499	9,550	9,550	9,550	9,787	9,787	9,787	10,797
Travel, Cut & Lift (lbs)	10,095	10,568	11,440	11,440	11,440	15,091	15,091	15,091	22,821
Net HP Used	147	154	83	125	166	110	165	220	249
Work MBtus	373,748	391,264	211,769	317,653	423,538	279,365	419,048	558,730	633,694
Gross HP	244.7	256.2	138.7	208.0	277.3	182.9	274.4	365.9	414.9
Fuel Use (GPH)	18.0	18.8	10.2	15.3	20.4	13.4	20.2	26.9	30.5

EPS will continue to find ways to streamline the trailer off-loading so that the full productivity of the harvester can be used. One possibility is the use of larger tracked trailers capable of hauling more than 50 tons and being side dumped. Farmers are already using 50-ton grain hopper trailers. The industry today uses trucks and trailers of many different hauling capacities. Building a large trailer for the harvester to haul whole trees from the harvest operation to a roadside landing or a nearby pre-processing site would seem reasonable.

Figure 20 shows how harvesting costs fall as oven dry tons per acre increases under 2 scenarios—trees planted for energy purposes versus those planted for fiber or timber purposes. In both cases, the costs fall as the diameter at breast height (dbh) of the harvested trees increases.

Figure 20: Harvest Costs as a Function of Productivity (dry weight harvested)



What becomes clear from operating the EPS harvester in lowering costs is its ability to run down a row at unprecedented speeds without stopping. This is because it is not encumbered by a small accumulator nor is there a need to back it up during cutting operations. In addition, the 900 horsepower harvester can forward 60 tons of wood to a landing at speeds up to 15 miles per hour using an agricultural-style trailer. This better resembles most farming operations where productivity is a function of forward speed, which translates to increased cutting and harvesting tonnage, rather than what is typical of normal logging operations.

3. TECHNOLOGY FINDINGS AND PROJECT LESSONS LEARNED

This section first covers the technology and takeaway lessons, divided into: (1) planting the hybrid poplars; (2) tending—weed control and fertilization--of the densely spaced tree plantings; and (3) the commercial demonstration of the EPS harvester. It concludes by discussing the long-term impacts of the Xcel Energy-EPS project.

Mechanizing the Planting of Hybrid Poplars

The key findings are covered in terms of (1) technology lessons in designing and operating the EPS injection planter and in the design, fabrication and testing of the injection planter and (2) results of machine planting compared to hand planting hybrid poplars.

Findings about the EPS Injection Planter

Key technology findings about the EPS injection planter include:

(1) The EPS prototype injection planter demonstrated that injection planting of hybrid poplars by a continuously moving machine could be performed with cuttings of 5/16 inch to 3/4 inch in diameter (standard industry size).

(2) The 6 row planter meets the weight requirements of standard category III 3-point hitch used on farm row crop tractors. The John Deere tractor with the 3-point hitch was able to load and unload the planter from a triple axel, goose-neck style trailer for longer haul distances.

(3) The injection planter trailered well behind the tractor using the dual-purpose gauge wheels and a ball hitch attached to the 3-point hitch on the tractor. The design allowed the operator to turn the dual gauge wheels 90 degrees and then trailer the planter length-wise both over the road and in the field for efficient field to field moving.

(4) EPS designed the injection planter for poplar hybrid cuttings ranging in diameter from 5/16 inch to 1 inch (larger than industry standard). So quality control at the nursery is very important. Oversized or undersized cuttings will result in skipped plantings. Users will have to obtain assurances of quality cuttings from nurseries or must sort the tree cuttings themselves.

(5) The EPS trigger system designed to release the injection rams when signaled worked very well. This allowed the on-board programmable controller to enable the satellite-guided trigger system to accurately control planting spacing.

(6) The use of rubber springs used to inject cuttings into the soil in the original design functioned well enough to plant 20 acres of hybrid poplars (35,000 cuttings). However, they were not robust enough to achieve the design planting speed. EPS has tested an entirely new spring system, using a gas spring, in its mechanical laboratory.

(7) The satellite signal from John Deere's Green Star system was too slow for the EPS application at 5 cycles per second and hampered high-speed operation. John Deere has now upgraded it to 10 cycles per second, which is now the *de facto* standard in the industry.

(8) After field-testing its injection planter, EPS added two design innovations—gas-driven springs in the slip injectors and an automatic slip feeder, which significantly lowers planting costs.

Machine Planting Versus Hand Planting Hybrid Poplars

EPS collected data enabling it to compare the efficiency of machine planting versus hand planting the hybrid poplar cuttings:

(1) Comparing machine and hand planting results showed that the EPS GPS-guided injection planter can accurately achieve the desired spacing between rows and trees, while hand planting results in a more random spacing within rows, (even when pre-marked by machine in advance). Accurate spacing both within and between rows is essential to facilitate tillage and herbicide spraying and mowing (both length-wise and across the field) for weed control without damaging or killing small trees.

(2) The sprouting of hybrid poplar cuttings was similar between hand and machine planted areas of the field. Furthermore, comparisons of initial growth of hybrid poplar cuttings planted by machine on both tilled and untilled cropland showed excellent success in the sprouting of hybrid poplars.

Weed Control, Fertilization, and Biomass Growth

Hybrid poplar production research has been ongoing since the late 1970's in Minnesota and other parts of the U.S. This section summarizes the results from EPS research on hybrid poplar production, which reflects the knowledge gained from its consulting with other hybrid poplar researchers and studying research literature on hybrid poplars.

Weed Control and Fertilization

Effective weed control and fertilization assists significantly in proper growth of hybrid poplar cuttings, as shown by these findings:

(1) To address aggressive weed competition from grass, EPS followed standard hybrid poplar establishment procedures—using pre-planting herbicides during site preparation and post-planting herbicides after planting. These generally proved effective for about 6 weeks. EPS strongly recommends the insertion of Roundup-ready genes in hybrid poplar clones. Glyphosate (Roundup) is the standard in the agricultural industry for corn, soybeans, and other crops. It greatly reduces costs and herbicide toxicity to establish tree farms.

(2) EPS found mowing to be an effective weed-control option that required it to make only minor modifications to commonly available equipment—a personal all-terrain vehicle (ATV) and a 4-foot wide brush-cutter. This was effective in controlling broadleaved weed competition but did not do as well in controlling grass competition.

Growth of Hybrid Poplars

EPS field work, communications with hybrid poplar specialists, and literature research revealed special insights into the growth of hybrid poplars:

(1) EPS's large field plantings confirmed that NM6, the most commonly available commercial clone in Minnesota, can achieve average annual yields in the range of 3 to 6 odt/ac/yr with the better-drained areas producing yields in the range of 4 to 6 odt/ac/yr, but lower yields on poorly drained alkaline soils. This confirms importance of selecting appropriate land for hybrid poplar production.

(2) Past research has shown that second rotation "coppice" harvest yields are normally 20 percent higher. This was taken into account in assessing costs of hybrid poplar production.

(3) EPS's analysis of relative yields among the clones in the clone trial shows that the commercial clones DN2, NE222, and DN34 may be able to attain growth rates similar to or better than NM6 on poorly drained, silty clay loam soils. So there is the possibility of using several different clones in future commercial projects. Appendix F provides further discussion on 5-acre clonal trials. It describes protocols used and yields of different clones planted as 1-year old rooted stock.

(4) Communications with other hybrid poplar investigators at the University of Minnesota—Natural Resources Research Institute (UM-NRRI) reveals that they have identified potentially important new clones in the past 5 years. These show potential for yields 30 percent to 60 percent higher than NM6 yields over a range of soil types. These clones are not yet commercially available.

(5) Literature research on hybrid poplar clone performance reveals that clones that show good performance on harsher sites are frequently also among the best performers on the better agricultural soils (Appendix G). So new clones selected for better performance in harsh conditions may be capable of producing yields in the range of 5 to 7 odt/ac/yr on better cropland, assuming best management practices.

(6) EPS's project experience in dealing with commercial nurseries suggests that a commercialization plan should include the establishment of nurseries internal to the business, which is the present strategy of many large commercial companies in the wood fiber business.

Commercial Demonstration of the EPS Whole Tree Harvester™

Being an entirely new design, the Whole Tree Harvester™ required EPS to address many challenging research issues. These included completing the fabrication of the harvester, designing the operational software, transporting it to the test site, and using it to harvest trees. The results are discussed in terms of (1) findings tied to WTH™ design and preparation for harvesting and (2) those discovered in using the WTH™ to harvest hybrid poplars.

WTH™ Design and Preparation for Harvesting

Key results related to the design of the EPS harvester and how it was prepared for harvesting include:

(1) EPS readily fitted the harvester to the front semi-tractor and rear tandems by rolling each custom-made assembly to the harvester-mounting flanges and bolting them in. Three large cylinders capable of extending from 90 to 120 inches are permanently attached to the harvester structure. These are used in conjunction with a small auxiliary hydraulic pump and motor called the "hydro pac," which is designed specifically for harvester maintenance and transport. This system remotely drives the tracks and enables proper structure alignment for bolt-up. It is also used for track alignment and maintenance.

(2) The relatively low cost hydro-pac was also very effective in propelling and steering (driving) the flanged and bolted front and rear track systems from the harvester unto a low-boy, semi-trailer for transport from the fabrication point to the field assembly site.

(3) The 3-bolt and 1-pin 2-axis universal joint harvesting head attachment system provides a quick and convenient way of removing and reattaching the harvesting head for transport.

(4) The successful transportation of the harvester from the fabrication site to the test site 160 miles away proves the machine can be disassembled, hauled over the highway, and reassembled in the field using innovative equipment and processes developed by EPS.

Using the WTH™ in Harvesting

The EPS field tests of the WTH™ revealed much practical information:

(1) The 2 self-sharpening, 49-inch circular blades on the harvesting head, sever trees cleanly and very efficiently. The system is designed to accept 2 more blades for precutting on large trees up to 30 inches in diameter. The blades are not motor driven, but turn due to the forward movement of the harvester while severing a tree.

(2) The high inertia of the harvester and the low cutting forces eliminate any discernible speed change of the harvester as it severs trees. It was thought that trees above 12 inches in diameter may cause pulsation in the operators cab, but this is no longer a concern. The forces measured on the cutting head were dropped from approximately 39,000 pounds to less than 6,000 pounds while severing a 13-inch tree by slightly changing the blade angle.

(3) The twin 450 HP engines on the WTH™ are easily able to propel the harvester at 6 miles per hour (mph) while providing auxiliary power to all systems including the accumulator system.

(4) EPS discovered that video monitoring of the harvester—through the use of multiple cameras—while driving it provides little or no benefit due to the small screen size and the inability to place a camera on the harvesting head directly in front of the trees. EPS will add auto steering "in the row" at a relatively low cost for future operations.

(5) Harvesting speeds up to 7 miles per hour produce record-breaking harvesting performance. The 2-speed operation of the 4-track motors also provide for high speed forwarding (12 to 14 miles per hour) when needed for forwarding operations.

The technology findings of the project demonstrate that it has met the specific targeted goals identified in the original proposal.

4. EPS AND THE GLOBAL AND LOCAL BENEFITS OF BIOMASS ENERGY

The present Xcel Energy-EPS project is only the latest step in EPS's research on biomass energy. This section briefly covers (1) EPS's mission and continuing research on commercializing biomass energy and (2) the important potential global and local benefits of biomass energy.

EPS's Mission and Continuing Research

Since the founding of Energy Performance Systems, Inc. in 1988, it has conducted a series of research projects intended to help commercialize biomass energy.

The EPS Mission

From its founding, EPS's mission has been to conduct research on hybrid poplars and to develop the technology necessary to enable biomass from these trees to produce competitively priced electricity and local jobs.

Past EPS Research

Working with Northern States Power (NSP), the Electric Power Research Institute (EPRI), the Universities of Minnesota and Wisconsin, the U.S. Department of Energy, and the U.S. Department of Agriculture Forest Service over the past 25 years, EPS has conducted a series of research studies to demonstrate the economic viability of biomass energy. The EPS Whole Tree Energy™ technology is founded on a system that calls for burning *dried whole trees* without cutting off the limbs or chipping the trees. This eliminates the cost of chipping the wood. Initially, many electric utilities were skeptical of the idea—especially because they expected the low combustion temperatures of wood would preclude producing the energy needed for efficient generation of electricity.

EPRI funded an EPS project to test whether a large volume of whole trees could be dried and burned efficiently enough to produce cheap electricity. For the research contract, EPS built a 100-foot tall stack of whole trees, dried them for a month, and burned the dried trees under controlled conditions to measure combustion efficiency. By removing 70 percent of the moisture in the whole trees, they burned at temperatures of over 2,400 degrees F, which demonstrated the necessary combustion efficiencies (Appendix B).

The issue for the feasibility of WTE™ then became whether fast-growing trees could be planted, grown, and harvested economically enough to produce competitive low-cost electricity.

The Xcel Energy-EPS Project

The current Xcel Energy-EPS project directly addresses the low-cost fuel questions emerging from EPS's combustion research on burning dried whole trees. EPS's recent field research demonstrates that hybrid poplar cuttings planted with its injection planter and the resulting whole trees harvested with the EPS Whole Tree Harvester™ can supply clean, uniform wood fuels that can lower the cost of renewable energy in Minnesota.

Financing the Xcel Energy-EPS Project. The total project cost was originally estimated to be $1.15 million, with the RDF portion at $976,000 or 85 percent of the total cost. The actual cost was about $2.7 million, with the RDF portion at 36 percent of the total cost. Part of the unforeseen additional project costs were due to the rapid increase in commodity prices and the corresponding increase in land rental rates after the project began (Appendix E).

The increase in land rental rates could have resulted in EPS abandoning the project. However, EPS, the company's board members, and the project contractor felt so strongly about the potential value of the technology that the research was continued. EPS covered the additional cost through a combination of loans to the project from EPS board members and investors, and in-kind labor of both EPS staff and subcontractors. The experience and technology knowledge gained by EPS while completing this project can be useful to a future wood-to-energy project development in Minnesota and elsewhere.

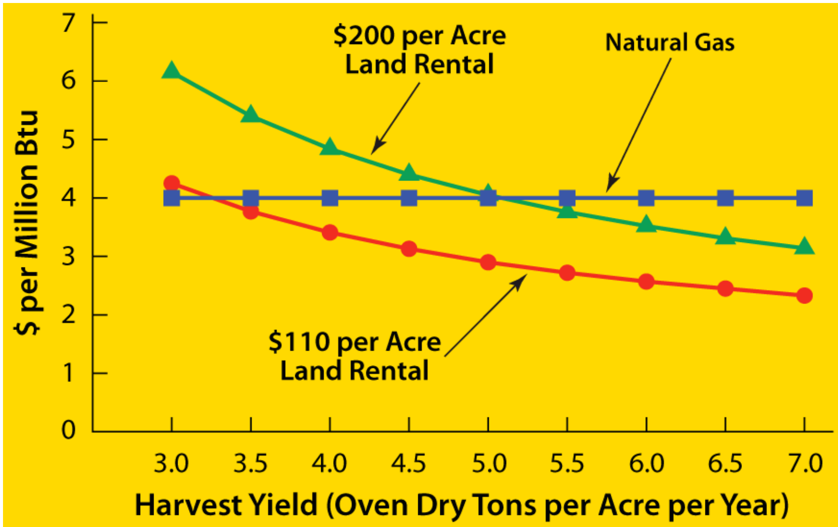
Environmental Benefits of an Integrated WTE™ Combustion Facility. EPS has also analyzed the potential miles driven per acre of crop production of both electric-fueled vehicles and ethanol-fueled vehicles (Appendix D). The comparison shows that with current technology, electric vehicles (fueled with wood-derived electricity) with similar driving characteristics as current light-duty vehicles can go up to 7 times further per acre of land than ethanol-fueled vehicles (using ethanol derived from corn). This offers a great environmental benefit by requiring much less land to provide for transportation needs of the United States. Also growing woody crops has many additional environmental benefits—such as reducing soil erosion, reducing chemical use, and providing greater landscape diversity and wildlife habitat.

If ethanol and commodity crop subsidies were to be eliminated or reduced to level the energy playing field, up to 30 million acres of U.S. land now used to raise corn for ethanol could alternatively be used to produce wood-energy crops. This also ensures profitability for landowners and offers affordable prices to utilities, assuming land rental rates continue at the prices of the land to produce corn and soybeans.

Cost of Wood Delivered by an Integrated WTE™ System. Figure 21 extends Figure 2 in the Executive Summary. It relates the delivered cost per Mbtu for various average annual biomass yields, in odt/ac/yr, for land planted with hybrid poplars. Two conclusions emerge:

(1) Comparing the cost of delivered hybrid poplar wood and natural gas on an energy basis shows that WTE™ produced wood (estimated to be deliverable over a 37 mile average haul distance for $4 or less per million Btu) is competitive with natural gas (delivered at or near $4 per million Btu) for generating electricity at a utility today.

Figure 21: Delivered Cost of WTE™ Wood Supply as a Function of Average Annual Yield



(2) The land needed to grow trees competes with that for growing corn on moderate to well-drained cropland and that rents annually for $200 per acre. Figure 21 shows that planting hybrid poplars on this $200-rent-per-acre cropland competes with $4 per MBtu natural gas using hybrid poplar clones that can achieve standing yields of 5 oven dry tons per acre per year within a 6-year period. With cropland rented annually for $110 per acre, Figure 21 shows that wood yields of 3.3 oven dry tons per acre per year could match the $4 per MBtu of natural gas. Using good management practices, NM6 has been able to achieve these yields on selected land. It is likely that new clones will become commercially available that show higher yields than the NM6 clones used in the EPS trials.

Biomass Energy: Global and Local Benefits

Central to the discussion of the feasibility of developing biomass energy is an understanding of its potential benefits—at both the global and local levels. As background to pursuing biomass energy in Minnesota, this section also briefly outlines a huge current effort in Mississippi to use wood to produce energy.

Global Benefits of Biomass Energy

Today, the majority of the world's energy experts believe that a major cause of global warming is the buildup of carbon dioxide in the earth's atmosphere. Producing energy by burning biomass is "carbon neutral"—the carbon dioxide added to the atmosphere from the wood combustion being exactly equal to that sequestered in plants and trees. Also, burning whole trees results in virtually no sulfur dioxide, very low nitrogen oxides, no toxic polyaromatic hydrocarbons, and very low particulate emissions. So generating electricity by burning whole tree biomass has clear environmental advantages over generating it from fossil fuels.

Local Benefits of Biomass Energy

Virtually every state and local government in the U.S. has a major focus today: Providing good jobs for its citizens. Mississippi is no different. Since 1990, the state has lost 10 of its 21 pulp and paper mills, leading to a 63 percent decline in employment for those firms—a loss of 6,300 jobs. The accompanying job loss by timber producers, loggers, and truckers carrying the trees multiplies the jobs lost in the pulp and paper industry by a factor of three or four. Mississippi has invested millions of dollars to help fund KiOr, a clean-tech startup company, which has built a refinery to convert finely ground woody biomass into crude oil. The technology is still being tested to see whether it can achieve the goal of producing competitively priced crude oil.

In contrast to this new wood-to-crude-oil technology in Mississippi, EPS believes that the technical results of the Xcel Energy-EPS project provide clear potential benefits to Minnesota. Two examples:

(1) **Providing a lower-cost wood energy supply system**. This project has developed new technology and methods to supply clean, uniform, wood fuels for energy that can lower the cost of renewable energy in Minnesota. The EPS WTE™ harvester can also lower the cost of supplying clean wood for fiber and timber to mills in Minnesota.

(2) **Producing clean electricity, while reducing greenhouse gas emissions**. This project also enhances the technical viability of burning dried whole trees to produce electricity. If the Minnesota legislature were to mandate increased attention to climate change, the project results provide a path to reduce greenhouse gas emissions without a significant increase in the price of electricity to Minnesota ratepayers.

In sum, the EPS vision is that the project will ultimately demonstrate the feasibility of using whole trees to produce competitively priced electricity in Minnesota, thereby providing new jobs for Minnesotans.

5. A VISION FOR COMMERCIALIZING THE XCEL ENERGY-EPS PROJECT RESULTS

The results of the Xcel Energy-EPS project demonstrated that the challenging technical goals identified in the original project proposal could be met. Also, the project created machines and hybrid poplar plantings that demonstrated the feasibility of a wood-energy project in Minnesota, the U.S., or globally. This section first identifies key project results that enhance commercialization possibilities and then describes EPS's initial commercialization activities.

Project Results Providing Commercialization Opportunities

The Xcel Energy-EPS project achieved important results in each of the three technology areas of: (1) planting the hybrid poplar cuttings; (2) weed control and fertilization; and (3) harvesting the trees that provide opportunities to commercialize elements of the WTE™ system.

Opportunities in Mechanizing the Hybrid Poplar Plantings

The speed with which the EPS injection planter can drive 10-inch hybrid poplar cuttings into unplowed fields presents important opportunities for commercialization:

(1) The project demonstrated that the EPS-guided injection planter can plant 6 hybrid poplar cuttings every 1.5 seconds, thereby reducing the cost of planting hybrid poplar cuttings to less than 50 percent of that of hand planting. This makes the injection planting of high-density tree crops (1,740 trees per acre) a cost-effective approach for quickly producing woody crop feedstocks for wood energy production in Minnesota.

(2) The EPS prototype injection planter can be made available for use in Minnesota (incorporating the modifications already tested in the EPS project) for commercial woody-crop production operations—from energy to pulp and timber industries.

(3) After field-testing its injection planter, EPS added 2 design innovations—gas-driven springs in the slip injectors and an automatic slip feeder, which significantly lowers planting costs.

Opportunities in Weed Control and Fertilization in Densely Spaced Tree Plantings

The EPS research on high-density tree plantings of NM6 and other clones offer significant competitive benefits:

(1) EPS gained and documented hybrid poplar yields as a function of soil types, dense plantings, and possible alternative clones for silty clay, loam soils. This valuable information can be used to support future cost-effective commercial application of high-density plantings of hybrid poplars for energy (Appendix H).

(2) The existing project tree plantings can serve as commercial sources of the NM6 clones if landowners are interested.

(3) EPS's high-density (5 foot by 5 foot) plantings allow the wood crop to approach or reach its maximum mean annual growth increment within 5 to 6 years. This establishes the feasibility of growing wood as a feedstock for energy. In this case, landowners will be paid rent every year, rather than waiting for returns from the longer-growth periods of 15 to 50 years, which is risky but is more common for wood provided to the fiber or timber industries.

Opportunities for Harvesting Trees with the High-Speed EPS WTH™

The opportunities for EPS's Whole Tree Energy Harvester (WTH™) follow from its efficiency and how clean the harvested trees are:

(1) The EPS Whole Tree Harvester™ can sever and accumulate trees at a rate of 1.6 trees per second, resulting in harvesting costs as low as $4 to $1 per green ton harvested.

(2) The EPS Whole Tree Harvester™ demonstrated the capability of producing clean, uniform, renewable, sustainable, and low-cost wood for the energy, fiber, or timber industries. This supports the viability of producing energy from wood in Minnesota.

(3) The EPS Whole Tree Harvester™ can be made available in Minnesota (with modifications depending on the industry application) in commercial operations to harvest wood for the energy, fiber, or timber industries.

The Future: First Steps and What's Next

EPS included the commercialization of its technologies in the metrics proposed for this project. It has put substantial effort into initial commercialization activities by making presentations to potential stakeholders to stimulate the adoption of the technologies being developed. In-person presentations were made directly to several equipment manufacturers, along with phone presentations to smaller equipment manufacturers.

Public presentations of both the planting and harvesting technologies were made at the Agricultural Equipment Conference in 2010. Marketing materials were prepared and distributed at a 2011 Biomass Trade and Power Conference. A contact there invited EPS to visit several locations and to meet individuals in Georgia who might have a special interest in the harvester. Posters and videos were shown at the Woody Crops Conference in 2012. In early 2013, EPS had a conference call with businesses from the U.S., Chile, Canada, and Poland, which were interested in its harvester for use in the energy, fiber, or timber industries within their respective countries.

None of these efforts have yet resulted in a commercial opportunity for the planter or harvester. But EPS believes that the completion of the last milestones and this final report on the Xcel Energy-EPS project provide new opportunities. It now has the data and analysis needed to make effective presentations about the benefits of the technology developed by the RDF Xcel Energy-EPS cost-shared project. Contacts with potential users and buyers of the technologies are continuing.

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6. APPENDICES

Appendix A: 2013 Annual Energy Outlook

Appendix B: Description of the Whole Tree Energy™ Technology

Appendix C: Clone Test Results from the Literature

Appendix D: Electric Vehicles Compared to Ethanol-Fueled Vehicles

Appendix E: Socioeconomic Climate at the Time EPS Rented Sites for the Xcel Energy-EPS Project

Appendix F: Background of Clone Comparison Trials

Appendix G: Short Rotation Poplar Clone Rankings in Harsh and Good Sites

Appendix H: Observations about Wood Crop Production for Energy

Appendix I: Glossary of Definitions and Abbreviations

Appendix A: 2013 Annual Energy Outlook

Figure A-1: Data from the 2013 Annual Energy Outlook Released December 2012; Prices in Dollars

Year	2010	2011	2012	2013	2014	2015
Prices (2011 dollars per unit)						
Brent Spot Price (dollars per barrel)	81.31	111.26	108.50	96.81	97.00	95.91
West Texas Intermediate Spot Price (dollars per barrel)	81.08	94.86	92.49	87.81	88.30	88.21
Natural Gas at Henry Hub (dollars per MBtu)	4.46	3.98	2.62	3.25	3.12	3.12
Coal, Minemouth (dollars per ton)	36.37	41.16	44.32	43.03	43.80	45.68
Coal, Minemouth (dollars per MBtu)	1.80	2.04	2.18	2.13	2.18	2.27
Coal, Delivered (dollars per MBtu)	2.42	2.57	2.63	2.56	2.62	2.64
Electricity (cents per kilowatt-hour)	10.0	9.9	9.4	9.2	9.2	9.2
Prices (nominal dollars per unit)						
Brent Spot Price (dollars per barrel)	79.61	111.26	110.43	100.20	101.81	102.21
West Texas Intermediate Spot Price (dollars per barrel)	79.39	94.86	94.13	90.88	92.68	94.00
Natural Gas at Henry Hub (dollars per MBtu)	4.37	3.98	2.66	3.36	3.28	3.32
Coal, Minemouth (dollars per ton)	35.61	41.16	45.11	44.54	45.98	48.68
Coal, Minemouth (dollars per MBtu)	1.76	2.04	2.21	2.20	2.29	2.41
Coal, Delivered (dollars per MBtu)	2.37	2.57	2.68	2.65	2.75	2.81
Electricity (cents per kilowatt-hour)	9.8	9.9	9.6	9.5	9.7	9.8

Year	2016	2017	2018	2019	2020	2021
Prices (2011 dollars per unit)						
Brent Spot Price (dollars per barrel)	97.00	99.08	101.20	103.36	105.57	107.83
West Texas Intermediate Spot Price (dollars per barrel)	91.33	96.08	98.70	101.26	103.57	105.83
Natural Gas at Henry Hub (dollars per MBtu)	3.57	3.70	3.96	4.05	4.13	4.26
Coal, Minemouth (dollars per ton)	48.69	48.85	48.89	48.84	49.26	49.73
Coal, Minemouth (dollars per MBtu)	2.39	2.41	2.42	2.43	2.45	2.48
Coal, Delivered (dollars per MBtu)	2.71	2.72	2.73	2.74	2.77	2.80
Electricity (cents per kilowatt-hour)	9.3	9.4	9.4	9.4	9.4	9.4
Prices (nominal dollars per unit)						
Brent Spot Price (dollars per barrel)	104.99	108.87	112.99	117.23	121.73	126.50
West Texas Intermediate Spot Price (dollars per barrel)	98.85	105.57	110.20	114.85	119.43	124.15
Natural Gas at Henry Hub (dollars per MBtu)	3.86	4.06	4.42	4.59	4.77	5.00
Coal, Minemouth (dollars per ton)	52.71	53.68	54.59	55.40	56.81	58.33
Coal, Minemouth (dollars per MBtu)	2.59	2.65	2.70	2.75	2.83	2.91
Coal, Delivered (dollars per MBtu)	2.94	2.99	3.05	3.10	3.19	3.29
Electricity (cents per kilowatt-hour)	10.1	10.3	10.5	10.7	10.8	11.0

Appendix B: Description of the Whole Tree Energy™ Technology

Energy Performance Systems, Inc. has spent 25 years developing Whole Tree Energy™, an electric power production technology that uses unprocessed whole trees for fuel. "Unprocessed" means that the wood is handled, transported, and delivered to the furnace as whole trees with tops, limbs, and trunks intact. The combustion system does not require chipping, shredding, or palletizing, and burns wood in a 3-stage, deep-bed, high-efficiency furnace resulting in very clean combustion.

Whole Tree Energy™ (WTE™) is a very cost effective renewable energy system. The technology is optimally designed to use fast-growing, short-rotation, farm-raised trees so that it qualifies as a closed-loop energy production system that is carbon-dioxide neutral. However, the fuel handling system is designed to handle whole trees of any length in 30-ton batches. The 8-foot wide by 8-foot deep conveyor can handle virtually any size or shape of tree including unprocessed, storm damaged yard trees—basically anything that can be loaded and hauled on a truck trailer.

As with all types of energy production, cost and the ability to keep up with demand is key to a sustainable energy source. WTE™ provides base load, dispatchable electricity (unlike other clean energy alternatives such as wind and solar energy) at a cost that is less than the cost of equivalently-sized, coal-burning plants and that is competitive with natural gas as a fuel.

Additional information on Whole Tree Energy™ and its associated technologies may be found at www.wholetreeenergy.com.

Appendix C: Clone Test Results from the Literature

Part 1: Summary of Tests of Top Clones

Figure C-1 summarizes test results of the top 12 clones across 12 locations in 4 North Central States. The figure shows that the DN5 and NM6 clones remain at the top of the list for both 7 and 10 years of growth, in terms of growth, yield, and disease resistance.

Figure C-1: Rank at Age 7 and 10

Rank	Clone: Age 7	Clone: Age 10
1 – best clone	**DN5**	**DN5**
2	**NM6**	**NM6**
3	DN164	**DN2**
4	DN17	DN70
5	DN182	**NM2**
6	DN70	DN182
7	**DN34**	DN131
8	145-51	**DN34**
9	**NE222**	DN17
10	DN55	145-51
11	DN154	**NE222**
12	DN177	DN74

Clones in bold are included in the tables in Part 2 below; Source: Netzer et al. 2002[1]

Part 2: Rankings of Selected on Specific Soils

Figures C-2 and C-3 compare the rankings of selected hybrid poplar clones on sites with silty clay loam or silty loam sites. In these figures, higher ranked rank numbers are best. Figure C-2 shows that for the Milaca, Minnesota site, the NM6 clone ranks highest on all 3 criteria: dbh, adjusted for survival, and adjusted for survival and disease.

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1 Selected sites and clones were extracted from Appendices in: Netzer, D.A.; Tolstead, D.N., Ostry, M.E., Isebrands, J.G.; Riemenschneider, D.E., and Ward, K.T. 2002. Growth, Yield, and Disease Resistance of 7- to 12-Year-Old Poplar Clones in the North Central United States. Gen. Tech. Rep. NC-229; St. Paul, MN; U.S. Department of Agriculture, Forest Service, North Central Research Station, p.31.

Appendix C (Continued)

Figure C-2: Site 1—Milaca, MN Silty Loam Site Planted 1989; Described as Being Somewhat Rocky; Septoria Cankering was Severe; No High Water Table

Clone	Number Measured	Standard Deviation	Rank by Dbh	Rank Adjusted for Survival	Rank Adjusted for Survival, Form, & Disease	Age
NM6	15	3.95	16.27	15.25	106.75	10
DN34	13	2.73	14.59	11.85	35.55	10
DN5	16	3.89	14.48	14.58	102.06	10
DN2	16	2.24	14.49	14.49	72.45	10
NM2	15	5.39	14.15	11.50	46.00	10
NE222	13	5.41	14.13	10.60	84.80	10

For the Mondovi, Wisconsin site, Figure C-3 shows that the DN2 clone is among the top 3 clones on all 3 criteria, while NM6 and NM2 are among the top 3 for 2 of the 3 criteria.

Figure C-3: Site 2—Mondovi, WI Silty Loam Site Planted 1990; Described as a Productive Agricultural on a Southwest Facing Slope

Clone	Number Measured	Standard Deviation	Rank by Dbh	Rank Adjusted for Survival	Rank Adjusted for Survival, Form, & Disease	Age
NM2	12	4.07	20.35	15.26	61.04	9
DN2	12	3.60	18.09	13.57	94.99	9
NM6	13	3.73	16.62	13.51	40.53	9
NE222	14	3.58	14.32	12.53	87.81	9
DN34	15	3.00	13.01	12.20	85.40	9
DN5	6	3.63	10.45	3.92	19.60	9

For the Fargo, North Dakota site, the limited number of results shown in Figure C-4 suggest the DN2 clone performs best on poorly drained clay soil that is subjected to frequent spring flooding.

Figure C-4: Site 3—Fargo, ND Silty Clay Site Planted 1987; Described as a Poorly Drained Clay with Frequent Spring Flooding*

Clone	Number Measured	Standard Deviation	Rank by Dbh	Rank Adjusted for Survival	Rank Adjusted for Survival, Form, & Disease	Age
DN2	13	3.79	19.58	15.90	111.30	12
NE222	11	3.64	17.31	11.90	71.40	12
DN5	15	3.53	17.08	16.01	96.06	12

*NM6 & NM2 not reported from this site

Criteria used for scoring rank, form and disease:

- Stem canker rating
- Clean, no cankers evident
- Light to medium cankers, no defects
- Medium to heavy cankers, no defects
- Dieback and breakage from cankering

- Form rating (not relevant to energy)
- Straight clean stems with few branches
- Slight stem sweep, medium branching, no defects
- Crooked stems, heavy branching, minor defects
- Stems deformed from sunscald damage and major stem defects

The point of selecting these sites and clones is to show that NM6 has ranked at top or fairly high even on silty clay or silty loam sites, but that clones DN2 and NE222 have been observed several times to be high in the rankings on silty clay or silty loam sites—this may be an additional clone to consider in western Minnesota.

Appendix D: Electric Vehicles Compared to Ethanol-Fueled Vehicles

Kenneth W. Ragland, Lynn L. Wright, and L. David Ostlie[2]

Summary

Annual vehicle miles traveled (VMT) per acre of land for an ethanol-fueled light duty vehicle is compared to a biomass powered electric vehicle with similar driving characteristics. This paper estimates that with current technology, electric vehicles with similar driving characteristics as current light duty vehicles can go 7 times further using an acre of land than ethanol-fueled vehicles. In 2007, twenty million acres of corn were dedicated to ethanol in the U.S. If this same land were dedicated to biomass to produce electricity for electric vehicles, 688 million miles (26% of U.S. VMT) could be realized assuming current technology. Future technological developments for electric vehicles are likely to be able to provide for the current 2.7 trillion VMT from 20 million acres.

Introduction

Global climate change and energy independence concerns are forcing the U.S. to embrace renewable energy. Electric Utilities are facing renewable energy portfolio mandates. The automobile industry is moving toward substituting gasoline with renewable fuels. The short-term focus of the industry is on ethanol-fueled vehicles, and hybrid electric vehicles are beginning to replace conventional gasoline fueled vehicles. Because of new developments in battery technology, all-electric vehicles are experiencing exciting new developments.[3] Plug-in hybrid electric vehicles (PHEVs) and all-electric vehicles (EVs) will increase the demand for electrical energy significantly during the next 15 years and much of this demand will be during off-peak hours so few new power plants will be required.[4]

Currently, millions of acres of farmland are being dedicated to corn based ethanol production. Ethanol and other types of liquid fuels from other types of biomass resources (e.g. crop and wood residues, dedicated energy crops, sugarcane bagasse, sugar beets, sorghum) are being intensively researched and production facilities are being built. But given the multiple demands for food, fiber, fodder and energy being placed on working crop and forest lands around the world, it is important to ask whether producing liquid fuels derived from corn and other forms of biomass is the most efficient use of the land. This paper will show that EVs powered with electricity from biomass need significantly less land for the same vehicle miles traveled (VMT) and have significantly less operating cost than liquid fueled vehicles. EVs can more efficiently displace a much greater amount of gasoline than can vehicles operating on renewable liquid fuels. New developments in battery technology will allow vehicles to have similar driving characteristics as liquid fueled vehicles.

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[2] Written in 2008 by Kenneth W. Ragland and L. David Ostlie: Energy Performance Systems, 12510 Fletcher Lane, Suite K, Rogers, MN 55374 and Lynn L. Wright: WrightLink Consulting, Ten Mile, TN.

[3] See websites www.teslamotors.com and www.phoenixmotorcars.com. See also "Nissan Plans Electric Car in U.S. by 2010, *The New York Times*, May 13, 2008.

[4] "Utilities Jump on Board to Plan for Plug-in Cars," *USA Today*, March 30, 2008.

The automobile industry is in a period of transition to flex-fuel vehicles capable of using petroleum and biomass derived liquid fuels to PHEVs, which can take some advantage of battery stored electricity, and soon to EVs. EVs are less complicated than PHEVs because EVs eliminate the engine, generator, transmission, driveshaft, differential gears, radiator, water pump, oil pump, fuel tank, fuel pump, and catalytic exhaust system. This paper will not consider flex-fuel vehicles and PHEVs because they are transition technologies and their effectiveness at displacing petroleum derived fuels and reducing greenhouse gases is limited. Rather, this paper will compare the energy requirements for biomass derived liquid fueled vehicles with biomass powered EVs. Of course, there are many ways, other than use of biomass, to generate renewable electrical energy such as wind, solar, hydro, geothermal, and wave energy, but our focus of comparison will be on how totally different vehicle technologies can result in dramatically different results in terms of miles traveled per acre of land.

Vehicle Transportation in the United States

The term ‘vehicle’ refers here to a light duty vehicle, defined as a passenger vehicle or light truck (including sport utility vehicles and vans) weighing less than 8,500 lb. A base year of 2006 is used in paper in order to have a consistent set of data. In 2006, the U.S. consumed 142 billion gallons of gasoline in light duty vehicles[5] that all together traveled 2.69 trillion miles.[6] The average mileage of these trips was 18.9 miles per gallon (2.69 trillion miles/142 billion gallons).

Vehicle mileage depends on vehicle weight and horsepower, engine and vehicle design, and driving patterns. A few characteristics of light-duty vehicles are shown in Figure D-1. Vehicle mileage has remained essentially constant during the last 20 years while vehicle weight and percent truck sales have increased. The driving cycles are used by EPA to certify the Corporate Average Fuel Economy (CAFE) fleet-wide fuel economy standards set by Congress.

Figure D-1: Characteristics of Light-Duty Vehicles for Four Model Years[7]

Parameter	1975	1987	1997	2006
Adjusted fuel economy (mpg)	13.1	22.1	20.9	21.0
Weight (lb)	4,060	3,220	3,727	4,142
Horsepower	137	118	169	219
0 to 60 time (s)	14.9	13.1	11.0	9.7
Truck sales (%)	19	28	42	50
Four wheel drive (%)	3	10	19	29

5 “Monthly Energy Review.” Table 5.11: Petroleum Products Supplied by Type, 2007, U.S. Energy Information Administration.
6 “Passenger Car and Light Duty Truck Fleet Average Characteristics”, 2006, National Highway Traffic Safety Administration.
7 Heavenrich, R. M., “Light Duty Automobile Technology and Fuel Economy Trends: 1975 through 2006,” Office of Transportation and Air Quality, U.S. Environmental Protection Agency, Washington, DC, 2007.

Appendix D (Continued)

In Figure D-1, the fuel economy values are based on 'real world' estimates provided by the federal government to consumers and are about 15% lower than the CAFE values. In 2008, 3 more driving cycles were added by EPA to account for: higher speeds and harder accelerations; air conditioning use under hot ambient temperature (95° F); and urban driving with colder ambient temperature (20° F). The combination of the 5 driving cycles bring the mileage in line with that shown in Figure D-1.

Representative driving patterns, defined by the EPA urban and highway driving cycles, are summarized in Figure D-2.

Figure D-2: Summary of EPA Urban and Highway Driving Cycles[8]

Characteristic	Urban Cycle	Highway Cycle
Trip type	Low speed in stop and go urban traffic	Free-flow traffic at highway speeds
Top speed (mph)	56	60
Average speed (mph)	20	48
Max. acceleration (mph/s)	3.3	3.2
Simulated distance (miles)	11	10
Cycle time (min)	31	12.5
Number of stops	23	0
Idling time (%)	18	0
Engine startup*	cold	warm
Vehicle air conditioning	off	off

*ambient temperature 68° F

Ethanol Production in the United States

In 2006, the U.S. produced 4.9 billion gallons of ethanol from 15.2 million acres of corn and in 2007, 6.5 billion gallons of ethanol were produced from 19.5 million acres of corn (Figure D-3). The *U.S. Energy Independence and Security Act of 2007* set the goal of producing 15 billion gallons of ethanol from corn annually by year 2022 plus an additional 21 billion gal/yr from biomass other than cornstarch by year 2022. Thirty-six billion gallons of ethanol/yr represents 25% of the light duty vehicle fuel on a volume basis but only 16.5% on an energy content basis. Fifteen billion gallons of corn-based ethanol might require 35 to 45 million acres of farmland depending on how the growing and conversion technology improves.

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8 See the U.S. Environmental Protection Agency website at www.fuelconomy.gove/feg/fe_test_schedules.

Appendix D (Continued)

Figure D-3: Ethanol Production from Corn in the United States

Parameter	2006	2007
Corn planted (million acres)[9]	78.3	93.6
Corn harvested (million acres)[See Footnote 9]	70.6	86.1
Corn harvested (billion bushels)[10]	10.5	13.1
Corn yield (bushels/acre)[See Footnote 10]	149.1	151.1
Corn for ethanol (billion bushels)[11]	2.1	2.95
Corn for ethanol (million acres; calculated)	15.2	19.5
Ethanol produced (billion gallons)[12]	4.9	6.5
Ethanol yield (gallons/ bushel; calculated)	2.3	2.2

Next, we consider how far an ethanol-powered vehicle can travel using 1 acre of land, and compare this to an all-electric vehicle using 1 acre of land to produce biomass and generate electricity. Then, we repeat this calculation using projected technological advances. Finally, we calculate the vehicle miles traveled that could be expected by dedicating 23 million acres to biomass both now and in year 2022.

Energy Conversion for Transportation Using Current Technology

Currently, corn grain is used to make ethanol, and from Figure D-4, we see that over half the energy content of the corn is lost in the conversion to ethanol. From the refinery ethanol is trucked to filling stations. Using these factors, the direct energy value of 1 acre of corn when delivered to the vehicle tank as ethanol is 25.5 million Btu/yr (Figure D-4). The energy needed to plant, grow, harvest, transport, and refine the corn is not included here but is discussed later.

Existing biomass electric power plants have typically used wood residues (forest, industrial, or urban) because of ready availability and relatively low cost in most areas. While those and other types of biomass will continue to be used to generate electricity in the future, this paper will assume the production of fast growing hybrid poplar and willow trees as the fuel for electric power generation. Currently, hybrid poplars and other fast growing hardwoods are grown commercially for fiber on 100,000 to 150,000 acres in the U.S.[13, 14]

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9 National Agricultural Statistics Service, U.S. Department of Agriculture. See the website www.nass.usda.gov/QuickStats.

10 U.S. Department of Agriculture, National Agricultural Statistics Service. Quick Stats Database. See the website www.nass.gov/Data_and Statistics/Quick_Stats/index.asp.

11 U.S. Department of Agriculture, Economic Research Service. Feed Grains Database: Yearbook Tables. See the website www.ers.usda.gov/Data/Feedgrains.

12 "Monthly Energy Review," Table 10.3: Fuel Ethanol Overview, 2007, U.S. Energy Information Administration. See the website www.eia.doe.gov/emeu/mer/renew.

13 Wright, L.L. and Berg, S., "Industry/Government Collaborations on Short-Rotation Woody Crops for Energy, Fiber, and Wood Products," *Bioenergy 96*: The Seventh National Bioenergy Conference: Vol.1, pp. 508-514.

14 See the website http://greenwoodresources.com/global-operations/north-america.asp.

Appendix D (Continued)

Figure D-4: Light Duty Ethanol-Fueled and Electric Vehicles—2006 Technology

Parameter	Corn-Ethanol	Poplar-Electric
In the Field		
Annual yield (bushels/acre)	149	—
Annual yield (dry tons/acre/yr)[a]	3.55	5.0
Higher heating value (Btu/lb)	8,250	8,600
Energy value (million Btu/acre/yr)	58.6	86.0
At the Refinery/Power Plant		
Conversion rate to ethanol/electricity[b]	2.3 gal/bushel	34%
Lower heating value (Btu/gal)	75,700	—
Energy value (million Btu/acre/yr)	25.9	29.2
Delivery to Vehicle		
Efficiency[c]	98.5%	92%
Energy value (million Btu/acre/yr)	25.5	26.9
Tank/Battery-to-Wheel		
Average efficiency	12.6%	75%
Vehicle Travel		
Fuel mileage with ethanol (miles/gal)	13.8[d]	—
Fuel mileage without regenerative braking (miles/million Btu)	182	1,080[e]
Fuel mileage with 40% regenerative braking (miles/million Btu)	—	1,280[f]
Fuel mileage (miles/kWh)[g]	0.62	4.4
Fuel mileage (miles/acre)	4,640[h]	34,400[i]

[a] density of shelled corn is 47.6 lb/bushel at 0% moisture
[b] see footnote 9; data from Table 18 and pg. 33
[c] see footnote 16, pg. 51 and Table 22
[d] 21.0 mpg × (75,700 Btu/gal/115,000 Btu/gal)
[e] 182 miles/million Btu × (75%/12.6%)
[f] 1,080 miles/million Btu × (1 + 0.461 x 0.40) [46.1% of energy output is used in acceleration]
[g] 3,413 Btu = 1 kWh
[h] 182 miles/million Btu × 25.5 million Btu/acre
[i] 1,280 miles/million Btu × 26.9 million Btu/acre

While commercial yields are not published, woody crop research plantings at operational scales and a range of tree densities per acre obtained yields of 4.5 to 7 dry tons/acre/year in all major regions of the country by the mid-1990's.[15] At the relatively close spacings believed to be

[15] Wright, L.L., "Production Technology Status of Woody and Herbaceous Crops," *Biomass and Bioenergy*, 6(3):191-210, 1994. Available at www.bioenergy.ornl.gov.

desirable for bioenergy, total tonnages of 25 dry ton/acre or more have been obtained within 3 to 6 years using selected varieties, good weed control, and other management practices (fertilization and pest control) as needed.

Electric utility power plants in the U.S. currently have an average efficiency of 34% based on the higher heating value (HHV)[16] and based on the lower heating value (LHV) the average efficiency is about 37%. The U.S. practice is to use the HHV while the European practice is to use the LHV for power plants. For the LHV, the heat of condensation of water vapor in the products of combustion is not included. Electricity is transmitted by wire to garages and charging stations. Considering these factors, the direct energy value of 1 acre of land when delivered in the form of electricity to the vehicle battery is 26.9 million Btu/yr (Figure D-4). The energy needed to plant, grow, harvest and transport hybrid poplar to the power plant is discussed later.

Next, consider the energy path from tank/battery to the vehicle wheels. The average mileage in 2006 in the U.S. for light duty vehicles was 21.0 mpg.[17] For ethanol, the effective mileage is reduced to 13.8 mpg because the lower heating value of ethanol is 75,700 Btu/gal compared to 115,000 Btu/gal for gasoline. The LHV is used by the engine industry.

The U.S. Department of Energy reports that the average tank-to-wheel efficiency of a gasoline or ethanol fueled vehicle is 12.6%.[18] Engine losses are 62.4%, standby idle losses are 17.2%, air conditioning and other accessories 2.2%, and driveline losses 5.6% for a total energy lost of 87.4%. The energy that powers the vehicle wheels (12.6% of the total input) goes to overcome aerodynamic drag (2.6%), rolling resistance (4.2%), and inertial acceleration (5.8%). The DOE reports that electric motors convert 75% of the energy from batteries to power the wheels,[19] whereas Tesla Motors reports that battery to wheel conversion is 80%.[20] These losses are primarily in the DC to AC inverter and motor.

An ethanol fuel mileage of 13.8 mpg is equivalent to 182 miles/million Btu or 0.62 miles/kWh (Figure D-4). For an energy value at the tank of 25.5 million Btu/acre, the fuel mileage footprint is 4,640 miles/acre. For the purpose of comparing an ethanol-powered vehicle to an EV, let us assume that the vehicle weight, aerodynamic drag, and rolling resistance are the same in both vehicles. The difference in the energy available to power the vehicles is reflected by the tank/battery-to-wheel efficiency (75% compared to 12.6%) so that fuel mileage for an EV is 1,080 miles/million Btu.

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[16] Wang, M., Wu, Y., and Elgowainy, A., "Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation" (GREET model), Center for Transportation Research, Energy Systems Division, Argonne National Laboratory, 2007.
[17] Heavenrich, R. M., "Light Duty Automobile Technology and Fuel Economy Trends.
[18] See the U.S. Department of Energy website at www.fueleconomy.gov.
[19] Ibid.
[20] Solberg, G., Tesla Motors. See the website www.teslamotors.com.

However, an EV has the capability of regenerative braking, and as noted in Figure D-5, 5.8% of the input energy is used for acceleration. Currently, regenerative braking can recover about 40% of the inertial energy so that there is an 18.4% improvement in the energy output of the wheels (Figure D-5). Therefore, an EV comparable to a 2006 ethanol powered vehicle has a fuel efficiency of 1,280 miles/million Btu and a mileage footprint of 34,400 miles/acre. In terms of land use, the EV can travel 7.4 times further on an acre of land than a corn-based ethanol-fueled vehicle of similar size and weight based on current technology.

Figure D-5: Energy Use at the Wheels[21]

Energy Use	Percentage Input Energy to Tank	Percentage Output Energy at Wheels
Aerodynamic drag	2.6%	20.6%
Rolling resistance	4.2%	33.3%
Acceleration	5.8%	46.1%
Total	12.6%	100.0%

Energy Conversion Assuming Technology Improvements

During the next 15 years, improvements in energy crops such as switch-grass, miscanthus, sorghum, sugar beets, sugarcane, hybrid poplar, willow, eucalyptus, and others will provide the opportunity for realizing considerable increases in yield, up to 12 dry tons/acre/year. Some sources cite higher yields, but in most cases with very high yields, there are certain implications to be discussed later.

In the not-so-distant future, biorefineries will be able to produce gasoline-like fuel with characteristics similar to today's petroleum based fuels. Biorefineries may be able to convert up to 50% of the energy in raw biomass into bio-gasoline. Advanced steam power plants over the next decade may begin to operate at conditions resulting in a net energy conversion efficiency of above 51% (based on the lower heating value).[22] Let us assume that within 15 years, biomass-fired electric power plants will achieve a net energy conversion efficiency of 42% (based on higher heating value) using advanced power plant technology. Note that the efficiency based on the higher heating value is about 4% lower than that based on the lower heating value.

Gasoline engines likewise have possibilities for improvement by adding various complexities such as variable valve timing and lift, selective cylinder deactivation during times of low load, turbo-charging and supercharging, direct fuel injection, and a continuously variable

[21] See Wright, L.L., "Industry/Government Collaborations…"
[22] Lubowski, R.N., et al., "Major Uses of Land in the United States," Economic Research Service, U.S. Department of Agriculture, May 2002.

transmission. The total improvement in efficiency from implementing all of these features is 38.5 % or 8.1 mpg (Figure D-6). EV's likely will show improvements in energy transmission from the battery-to-wheel due to improved conversion from DC to AC, improved traction motors, and increased recovery of energy from regenerative braking.

Figure D-6: Energy Improvements for Spark Ignition Engines and Transmission[23]

Method	Potential Efficiency Improvement	Fuel Economy Increase* (mpg)
Variable valve timing and valve lift	5.0%	1.0
Cylinder deactivation	7.5%	1.6
Turbocharging and supercharging	7.5%	1.6
Direct fuel injection	4.5%	0.9
Integrated starter/generator for idle shutoff	8.0%	1.7
Continuously variable transmission	6.0%	1.3
Total	38.5%	8.1

*based on an average fuel economy of 21 mpg

With regard to driving characteristics, light duty vehicles hopefully will have less weight through use of advanced materials and smaller size, lower aerodynamic drag, and slightly lower rolling resistance. The most important factor is reduced weight. Let us assume that the average vehicle weight is reduced by 15% from 4,142 lb. to 3,520 lb. Also, assume that the aerodynamic drag is reduced by 10%. Then the vehicle efficiency is improved by 40% (Figure D-7) or 8.4 mpg. If the measures in Figures D-6 and D-7 are implemented, the mileage for light duty vehicles will increase 78.5% from 12.6% to 22.5% for ethanol and from 21 mpg to 37.5 mpg for biogasoline. By way of comparison, the *Energy Independence and Security Act of 2007* mandates a CAFE standard of 35 mpg by year 2020 for new light duty vehicles.

Figure D-7: Energy Improvements in Vehicle Use at the Wheel

Energy Use	Input Energy to Tank	Output Energy at Wheels	Efficiency Improvement
Aerodynamic drag	2.6%	20.6%	10%
Rolling resistance	4.2%	33.3%	15%
Acceleration	5.8%	46.1%	15%
Total	12.6%	100.0%	40%

[23] See the U.S. Department of Energy website at www.fueleconomy.gov.

Appendix D (Continued)

Following a similar procedure as used in Figure D-4, we see that 15 years from now, technological improvements in the fuel production and the vehicle design, summarized in Figure D-8 below, can potentially lead to a 710% improvement in miles traveled from an acre of land for biogasoline fueled vehicles compared to corn based ethanol and a 390% improvement in the miles/acre for EV's. But even with these gains, an EV of similar vehicle characteristics uses 400% less land than a biogasoline-fueled vehicle.

Figure D-8: Light Duty Biogasoline and Electric Vehicles—Future Technology

Parameter	Biomass-Biogasoline	Hybrid Poplar-Electric
In the Field		
Annual yield (dry tons/acre)	12	12
Higher heating value (million Btu/ton)	17	17
Energy value (million Btu/acre/yr)	204	204
At the Refinery/Power Plant		
Conversion rate to biogasoline/electricity	50%	42%
Energy value of biogasoline/electricity (million Btu/acre/yr)	102	86
Delivery to Vehicle		
Efficiency	99%	93%
Energy value (million Btu/acre/yr)	101	80
Tank/Battery-to-Wheel		
Average efficiency	22.5%	85%
Vehicle Travel		
Fuel mileage with biogasoline (miles/gal)	37.5	—
Fuel mileage without regenerative braking (miles/million Btu)	326	1,224[a]
Fuel mileage with 80% regenerative braking (miles/million Btu)	—	1,675[b]
Fuel mileage (miles/kWh)[c]	1.1	5.7
Fuel mileage (miles/acre)	33,000[d]	134,000[e]

[a] 1,080 miles/million Btu × 85%/75% = 1,224 [using Figures D-4 and D-8]
[b] 1,224 miles/million Btu × (1 + 0.461 × 0.80) [46.1% of energy output is used in acceleration]
[c] 3,413 Btu = 1 kWh
[d] 326 miles/million Btu x 101 million Btu/acre
[e] 1,675 miles/million Btu × 80.0 million Btu/acre

What if 20 Million Acres Were Permanently Dedicated to Bioenergy?

Since about 20 million acres of land in the U.S. was dedicated to producing corn for ethanol in 2007, and since this amount or more is likely to be repeated in 2008, it is reasonable to ask how many vehicle miles traveled can be provided by 20 million acres of dedicated cropland. In the U.S., roughly 442 million acres are used for agricultural crops and cropland pasture, 657 million acres for forests, and 587 million acres for grassland, pasture and range.[24] Twenty million acres represents 4.5% of the U.S. land suitable for agriculture.

Using the U.S. VMT for 2006 for light duty vehicles of 2.69 trillion miles traveled, the vehicle mileage in miles/acre from Figures D-4 and D-8 shows that dedicating 20 million acres of land to bio-energy can completely provide for our VMT needs in the U.S. if EVs become the dominant technology (Figure D-9). However, ethanol-fueled and bio-gasoline-fueled vehicles fall far short of meeting VTM even with projected technological improvements in fuel production and vehicle performance.

Figure D-9: Vehicle Miles Traveled Using 20 Million Acres of Dedicated Land

Vehicle Type	Miles/ Acre	Total Green VMT	% U.S. VMT*
Ethanol (current technology)	4,640	93 billion	3.5%
All-electric (current technology)	34,400	688 billion	26%
Biogasoline (new technology)	33,000	660 billion	25%
All-electric (new technology)	134,000	2.68 trillion	100%

*based on 2.69 trillion VMT

Operating Cost Comparison

For the assumed off-peak residential electric rate and assumed liquid fuel cost shown in Figure D-10, the cost of electricity to operate an electric vehicle is 20 times cheaper than using E85 (85% ethanol plus 15% gasoline). Assuming a vehicle is driven 15,000 miles/yr, an EV could save $3,000 per year in operating energy cost compared to an ethanol-fueled vehicle of similar size and weight based on current technology.

[24] Lubowski, R.N., "Major Uses of Land in the United States."

Appendix D (Continued)

Figure D-10: Cost of Energy to Operate a Vehicle

Vehicle Type	Unit Cost	Mileage	Cost/ 15,000 Miles
Gasoline[a]	$3.60/gal	21.0 mi/gal	$2,570
E85[a]	$2.95/gal	13.8 mi/gal	$3,200
All-electric	$0.13/kWk	5.0 mi/kWh	$390
All-electric-off peak[b]	$0.05/kWh	5.0 mi/kWh	$150

[a] April 2008 (see www.eere.energy.gov.)
[b] residential rate

Discussion

The above calculations track the primary energy paths for liquid-fueled and all-electric light duty vehicles powered with biomass. But these calculations do not account for the secondary energy use required to grow, harvest, and transport the bio-energy crops, and the additional energy to operate the bio-refinery. Many calculations have been reported on the energy balance of ethanol production, and definitive calculations are provided by the GREET model.[25] Corn-based ethanol requires fertilizer production, corn farming, corn transportation, ethanol production at a refinery, and transportation to the refueling station, all of which use fossil fuel input. According to the GREET calculations, corn-based ethanol requires 0.78 million Btu of fossil energy for each 1 million Btu of ethanol delivered.[26] This compares to gasoline, which requires 1.25 million Btu of fossil energy for petroleum recovery, transport, refining, and gasoline transport to the refueling station for each 1 million Btu of gasoline delivered.[27] In contrast, willow trees, for example, can be grown, harvested, and transported to the biomass power plant for approximately 0.07 to 0.10 million Btu of fossil energy input for every 1 million of electricity generated.[28] Thus, the secondary energy requirements to produce woody biomass for electricity are nearly 10 times less the secondary energy requirements to produce ethanol.

An ideal biomass crop for electricity generation should have the following features:

- Be easy to propagate, plant and harvest
- Be adaptable to a wide range of soil types and temperature conditions
- Require low nutrient inputs (nitrogen phosphorus, and potassium)
- Require low micronutrient input (copper, manganese, zinc, iron)
- Have good pest and disease resistance

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[25] Wang, M., “Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation.”
[26] Wang, M., “Ethanol: The Complete Energy Lifecycle Picture,” Center for Transportation Research, Argonne National Laboratory. See the website http://www.transportation.anl.gov/pdfs/TA/345.pdf.
[27] Ibid.
[28] Keoleian, G.A. and Volk, T.A., “Renewable Energy from Willow Biomass Crops: Life Cycle Energy, Environmental and Economic Performance,” *Critical Reviews in Plant Sciences*, 24:385-406, 2005.

- Have good drought tolerance
- Have low invasiveness potential
- Provide good ground cover for soil retention
- Generate deep roots for soil building and carbon sequestration
- Provide good habitat for birds and mammals
- Have low levels of nitrogen in plant tissue when harvested
- Have high energy content per unit of dry mass

While it is difficult for any potential biomass crop to meet all of the above criteria, perennial woody crops do better than most possible alternatives. Woody crops may not always have the highest yields, but they are preferable for electric power generation because they always have higher energy content per unit of biomass than herbaceous crops. Woody crops also have lower inorganic content than herbaceous crops and hence less slagging of boiler tubes. Woody crops usually require less fertilizer and herbicides, have deeper roots, provide better erosion control, and create better wildlife habitat and landscape diversity than perennial grasses. Nitrogen in the leaves is returned to the soil with leaf fall each year and nutrients in the stems are trans-located to the roots in winter. The year round harvest window minimizes storage requirements for woody crops.

For electric power generation with biomass, minimizing fuel handling and processing prior to conversion and provision for drying the fuel is important for improving efficiency. Energy Performance Systems, Inc. has promoted a method whereby hybrid poplar trees are harvested and transported in whole form without chipping. Since the flue gas contains no sulfuric acid, waste heat for drying can be extracted from the flue gas. At the power plant site, the trees are dried in a drying dome with waste heat for 1 month and then utilized as whole tree segments in a specially designed combustion section of a steam power plant.[29] Particulate and nitrogen oxide emissions controls are used, and ash is collected, palletized, and returned to the bio-energy field as slow release fertilizer. The process is closed-looped, renewable and sustainable.

Searchinger, et al., have argued that taking a large amount of land in the U.S. out of conventional agricultural and forestry production causes environmentally-sensitive land elsewhere in the world to be cleared and put into replacement production of crops that are displaced by the energy crops in the U.S., thus doing more harm than good.[30] Our approach is to consider the benefit of an alternative energy product from the land now producing grain for ethanol. In 2007, the U.S. used 19.5 million acres of corn to produce 6.5 billion gallons of ethanol, which accounted for only 3.5% of VMT (Figure D-9). The 2007 *U.S. Energy Independence and Security Act* goal of producing 15 billion gallons of corn-based ethanol by

Appendix D (Continued)

[29] "Economic and Technical Feasibility of Modifying the Minnesota Valley Power Plant to Utilize Whole Trees as the Primary Fuel Source, Xcel Energy final report submitted by L, D. Ostlie, Energy Performance Systems, May 2003. See also the website www.energyperformancesystems.com.

[30] Searchinger, T., et al., "Use of US Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land Use Change," *Science Express*, Feb. 7, 2008.

year 2022 could lead to 35 million acres or more of U.S. farmland being dedicated to corn for ethanol. Our calculations show that electric vehicles supplied with biomass power from 20 million acres could meet a very large portion of U.S. transportation needs; since this land has already being used for energy, no additional land is needed. Even if less land were dedicated to energy as a result of addressing the concerns raised by Searchinger and others, woody biomass-based renewable electricity used by electric vehicles could still go a long way toward meeting our light duty vehicle transportation needs in the U.S.

Biofuels offer a path for partial energy independence and greenhouse gas reduction in the light duty vehicle transportation sector of the economy. However, electric vehicles offer a far more efficient energy path during the next 15 years leading to more complete energy independence. Rapidly developing battery technology is speeding the advent of all-electric vehicles with the same transportation characteristics as we have become accustomed to with conventional vehicles. Using the fuel costs shown in Figure D-10 and assuming that 75% of the battery charging is done at off-peak rates, the savings to power the current U.S. VMT would be $530 billion per year compared to using ethanol.

Appendix E: Socioeconomic Climate at the Time EPS Rented Sites for the Xcel Energy-EPS Project

The passage of the *Renewable Fuels Standard in the Energy Policy Act of 2002* caused rapid changes in both agricultural and energy markets that made implementation of the project plan more difficult than anticipated. In 2004, the corn-based ethanol market was in its third year of rapid expansion and most of the biorefineries were being located in the Midwestern corn belt, including southern Minnesota. Figure E-1 shows the rapid increase in U.S. ethanol production, especially from 2000 to 2012.[31]

Figure E-1: U.S. Ethanol Production—1980-2012

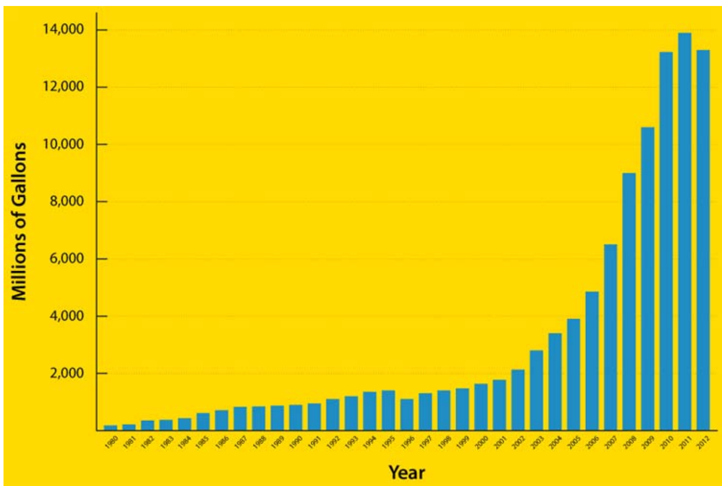
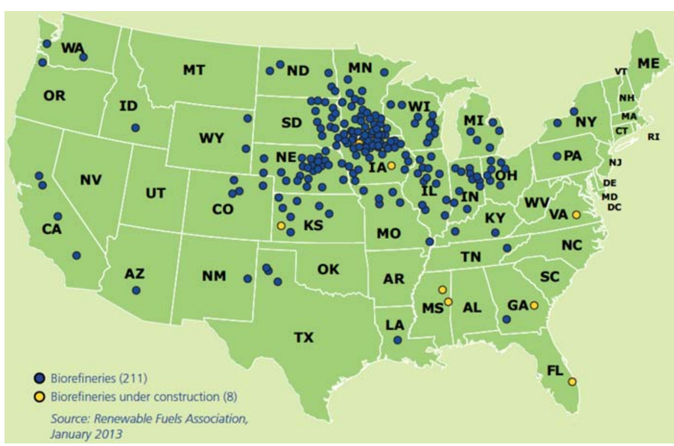


Figure E-2 shows U.S. ethanol plant locations—concentrated in southern Minnesota.[32]

Figure E-2: Location of Ethanol Plants in the U.S.—2013



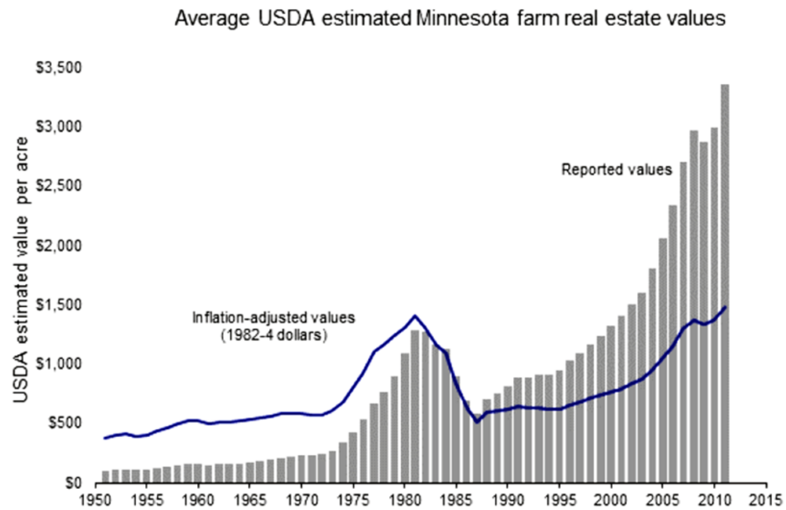
[31] "Historic U.S. Fuel Ethanol Production—1980 to 2012, Renewable Fuels Association. See http://www.ethanolrfa.org/pages/statistics.

[32] "U.S. Ethanol Biorefinery Locations," Battling for the Barrel: 2013 Ethanol Industry Outlook, Renewable Fuels Association, p.3. See http://www.ethanolrfa.org/pages/annual-industry-outlook.

Appendix E (Continued)

Figure E-3 shows the results of Figures E-1 and E-2—the increased U.S. production of ethanol, the heavy concentration of ethanol plants in southern Minnesota, and the dramatic rise in the value of Minnesota farmland since about 1995. The blue line in Figure E-3 shows that in terms of 1982-84 dollars, the average price of farmland doubled from about $750 to $1,500 per acre from 2000 to 2011.

Figure E-3: Average Real Estate Values of Minnesota Farmland ($/Acre)



Source: Steven J. Taff, Department of Applied Economics, University of Minnesota from Minnesota Real Estate Sales, 2011; US Department of Agriculture.

As a result, farmland prices were rising very rapidly by 2005 when the Xcel Energy-EPS project was approved and EPS started its search for suitable farmland. This price increase created a large hurdle for renting farmland, especially at the rental rates used for the proposed research cost estimates (based on 2003 and earlier rates). EPS contracted both print and radio broadcast media to acquire rental land. In order to meet contract obligations, EPS was ultimately forced to establish the hybrid poplar production trials on farmland of lower quality than had been assumed when establishing the yield goals and measures of progress for the Xcel Energy-EPS project.

The Graceville fields were the only fields that EPS could locate within the time constraints of meeting the contractual obligations of the Xcel Energy RDF contract in 2007. While the landowner was very interested in and supportive of the project and donated many hours to the planting effort, the only land that he could reasonably take out of grain production and rent (considering economics) was marginal-quality land. The rental rates of $110 per acre were very reasonable, given the rates on higher-quality land. But unfortunately, that rate was at the upper end of the rental rates EPS had anticipated paying when the proposal was submitted in early 2005.

Appendix F: Background of Clone Comparison Trials

Normal Protocols for Establishing Clone Comparison Trials

The Iowa State University (ISU) researchers followed normal first-stage experimental rooted clone comparison protocols for evaluating the 10 clones established in the project's 5-acre clone comparison trial near Dumont, MN. Thus, the trial was established with hybrid poplar clones with 1-year old root systems that were lifted from the ISU nursery beds (while dormant) and both the stems and roots cut back prior to planting. While stems normally are 8 inches or taller, they were about 24 inches tall in the EPS clone trials. The roots were trimmed to a length of about 7 inches. These rooted cuttings were bedded into 18-inch deep by 8-inch diameter holes, leaving about 16 inches of stem above ground. Each plot contained 25 trees and the center 9 were measured for yield estimates. Only after information is gained on rooting in several soil types are clones normally compared using unrooted cuttings or slips in large yield plots.

Reasons for Using One-Year Rooted Cuttings in the Xcel Energy-EPS Project Trial

The clone comparison trial was not originally proposed by EPS but was added to the project after observing that MN6 did not perform well in some areas of the commercial-scale field plantings. The results of this trial were intended only to provide preliminary information on possible alternative clones for western Minnesota. ISU breeders were contacted because they had been attempting to select clones with better suitability for poorly drained, alkaline soils and had some new clones available for testing. Because some clones had variable or unknown rooting characteristics (Figure F-1) and the site could not be easily protected from weed competition and deer browse, the year-old rooting cutting procedure was considered to have the best chance of assuring survival of the clones.

Figure F-1: Rooting Information and Trial Status on the Clones from the EPS Clonal Trial

Clone Name	Parentage	Rooting Information	Status in Trial
NM6	*p. maximowiczii x p. nigra*	Excellent	Commercial standard—widely planted
DN34	*p. deltoides x p. nigra*	Good	Older commercial standard
DN2	*p. deltoides x p. nigra*	Excellent	Commercially available
NE222	*p. deltoides x p. nigra*	Excellent	Commercially available
D105	*p. deltoides*	Good w/ soak	Commercially available
DN177	*p. deltoides x p. nigra*	Excellent	Commercially available
ISU 25-35	*p. deltoides x p. deltoides*	Good w/ soak	New hybrid clone from breeding
91 × 01-03	*p. deltoides x p. deltoides*	Not known	New hybrid clone from breeding
80 × 01112	*p. deltoides x p. deltoides*	Good w/ soak	New hybrid clone from breeding
P. deltoides	*p. deltoides*	Variable	New selection from natural stands

Only the top 5 clones in Figure F-1 had sufficient survival of the center 9 clones to be included in the analysis of estimated yield potential. The clone trial results indicate that these clones should be compared in larger block trials using unrooted cuttings and management similar to commercial conditions.

Appendix G: Short Rotation Poplar Clone Rankings in Harsh and Good Sites[33]

Figure G-1: 5 to 6 Year Old Clone Rankings (planted in 1987-1988)

Clone[34] (5 to 6 years old; planted in 1987-1988	Harsh Sites		Good Sites	
	Reliability (%)	Number of Sites	Reliability (%)	Number of Sites
DN5	100	3	100	4
NM6	100	3	100	4
DN70	100	3	100	4
DN2	84	6	100	8
DN34	84	6	100	8
I45-51	84	6	100	8
DN17	66	6	100	8
NE222	66	6	87.5	8
DN38	66	3	100	4
DN177	66	3	100	4
DN170	66	3	100	4
I476	66	3	50	4
DN128	66	3	0	4
NE264	50	6	100	5
DN9	33	6	87.5	8
DN74	33	3	100	4
NM2	33	3	100	4
NC5377	33	3	100	4
DN16	33	6	75	8
45-1	33	6	75	8
DN174	33	3	75	4
DN131	33	6	62.5	8
DN173	33	3	50	4
DN179	33	3	50	4
DN55	16	6	100	8
DN182[35]	16	6	100	8
DN1	0	3	100	4
SIOUX[34]	16	6	87.5	8
DN181	0	3	75	4
NE35	16	6	62.5	8
NE295	0	6	62.5	8
DN18	16	6	50	8
DN106	0	3	50	4
NE49	0	6	50	8
DN114	0	6	50	8
NE300	0	3	50	4
NC5339	0	3	50	4
DTAC7	0	3	50	4
DTAC26	0	3	50	4

[33] Hansen, Edward A., et al., "Field Performance of Populus in Short-Rotation Intensive Culture Plantation in the North-Central U.S.," Research Paper NC-320, St. Paul, MN, U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station.

[34] Clones with > 50% reliability on at least 1 of 2 clusters of sites. Where "reliability" is the percent of sites on which a given clone showed good growth relative to the other clones and fair resistance to Septoria through age 5 or years.

[35] Clones in commercial production at this time (includes all shaded clones above the line).

Appendix H: Observations about Wood Crop Production for Energy

Production of hybrid poplar trees is in an early stage of development compared to production of corn and soybean crops, which also once had very specific soil requirements and weed control issues. Lessons learned from considering the development track of corn and soybeans are that: (1) continued selection for more adaptable hybrid poplar clones is important and (2) breeding and insertion of the "round-up ready" gene could both reduce weed pressure and also assist in increasing the adaptability of hybrid poplar trees to a broader range of soil types. This will result in increased yields and reduce tending costs.

The effort required to identify land available for rent for the Xcel Energy-EPS funded research revealed much about the effects of agricultural subsidies and energy policies on cropland prices. EPS found that cropland of the type needed to meet the yield goals proposed in 2004 using NM6 was no longer available at the anticipated price of $110 per acre when funding became available in late 2006 (Appendix E). The loss of the test site in south-central Minnesota, which was the quality desired by the Xcel Energy-EPS project, was mainly related to the increasing value of cropland due to increased demand for corn used for ethanol. The finding is that, without federal policy changes regarding subsidies for corn and ethanol, wood fuel prices higher than the $2.80 per Mbtu originally proposed in 2004 are necessary to allow for the increased rental payments required to compete with returns to the land expected from commodity crops. Natural gas is currently the most frequent competitor to the use of biomass energy and the delivered cost of natural gas is closer to $4.00 per Mbtu.

It would traditionally be expected to take 3 to 5 years for commercial nurseries to get the production beds planted that will be the source for commercial scale supplies of new hybrid poplar clones. However, it could happen much more rapidly if the demand were created by energy production facilities. A fuel supply plan prepared by Energy Performance Systems for a potential electric power production facility identified mechanisms being used by industry, which could produce a large supply of cloned hybrid poplars within 2½ years. This involved using leaf tissue and nurseries both in the U.S. and in Brazil for the scale-up. The cost of such an endeavor was included in the capitalization of the proposed power plant. The EPS plan capitalized more than $30 million for scale-up, land rental, and planting to meet the project schedule.

Appendix I: Glossary of Definitions and Abbreviations

- **Btu—**British thermal unit
- **CAFE—**corporate average fuel economy, the fleet-wide fuel economy standards set by the U.S. Congress
- **Checked pattern—**the specified distances between cuttings in planting hybrid poplars requiring fixed spacing (like 5 feet by 5 feet) between cuttings
- **Coppice—**to cut trees near the ground in order to allow them to regrow
- **CRP—**U.S. Department of Agriculture Conservation Reserve Program that keeps land out of cultivation
- **Cuttings—**10-inch long unrooted slips of hybrid poplar, used in planting a hybrid poplar tree farm
- **D105—**hybrid poplar clone, *populus deltoids*
- **dbh—**the diameter at breast height (standardized to 4.5 feet above ground level) is the widely used measure of the growth of recently planted trees
- **DN2—**hybrid poplar clone, *populus deltoids x populus nigra*
- **DN34—**hybrid poplar clone, *populus deltoids x populus nigra*
- **Dry tons—**in terms of trees, the weight, in tons, of trees after drying, which is approximately half of the weight of green tons due to the loss of moisture
- **EPS injection planter—**a GPS-guided planter developed by EPS that uses hydraulic injection technology, which simultaneously plants 6 hybrid poplar cuttings
- **Establishment—**as an agricultural term, the work performed from the time of planting to when the resulting growing trees do not require sustained weed control
- **EV—**all-electric vehicle
- **fps—**feet per second
- **GPS—**global positioning system
- **Green tons—**in terms of trees, the weight, in tons, of trees when they are harvested, which includes the moisture in the trees that makes up approximately half of their weight
- **HHV—**higher heating value, an efficiency measure for electric utility power plants
- **HP—**horsepower
- **Hybrid poplar tending—**all crop management activities applied to a hybrid poplar planting. This may include weed, pest and disease control as well as fertilization and monitoring for other damage such as deer browse
- **LHV—**lower heating value, an efficiency measure for electric utility power plants
- **MAI_{max}—**mean annual increment of biomass growth by weight

Appendix I (Continued)

- **MBtu—**millions of British thermal units
- **mpg—**miles per gallon
- **MS2, MS4, etc.—**examples of specific Xcel Energy-EPS project milestone reports
- **NE222—**hybrid poplar clone, *populus deltoids x populus nigra*
- **NM6—**hybrid poplar clone, *populus maximowiczii x nigra*
- **odt—**oven dry tons
- **odt/ac—**oven dry tons per acre
- **PHEV—**plug-in hybrid electric vehicle
- **RDF—**renewable development fund, a research program passed by the Minnesota legislature to encourage research on clean energy
- **Slips—**same as "cuttings"
- **VMT—**annual vehicle miles traveled
- **Xcel Energy-EPS project—**Xcel cost-shared Energy Performance Systems, Inc. project
- **WTE™—**Whole Tree Energy™ is a renewable energy system that includes the use of crop-raised whole trees in biomass power plants to produce clean energy
- **WTH™—**Whole Tree Harvester™ is a large mechanical harvester developed by EPS that cuts trees, transports them up an incline, and drops them onto a truck for transportation