U.S. DEPARTMENT OF ENERGY
Energy Efficiency & Renewable Energy

INL/EXT-10-20074

Workshop Report
High-Yield Scenario Workshop Series

December 2009

FOREWORD

The "High-Yield Scenario" and why it is necessary

The 2005 Billion-Ton Study[a] (BTS) estimates the amount of biomass resource that could potentially be available after other market demands for biomass resources are met. Preliminary assessments identified more than 1 billion tons of biomass available annually from agricultural residues, woody residues, and herbaceous and woody energy crops—a volume sufficient to help offset 30% of U.S. transportation fuel consumption.

The BTS relied on estimates of future production capability based on data and technology that were available at the time of the assessment. Since the release of the BTS, research efforts in both public and private sectors have contributed to a clearer understanding of the constraints and opportunities for establishing a sustainable, commodity-scale biomass market capable of supporting a bioenergy industry.

Some studies suggest that soil productivity limitations that reduce the amount of resource available under the current state of technology may be overcome, to an extent, with innovative tillage and cropping regimes. Others report that advancements in crop development and management suggest greater yield potential for some resources than those projected in the BTS assessment.

The "High-Yield Scenario" workshop series was sponsored by the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy (DOE/EERE) Biomass Program to identify and discuss the challenges associated with substantially increasing production of lignocellulosic biomass resources, such as agricultural crop residues (in particular, corn stover) and herbaceous and woody energy crops, to sustainably supply feedstock for biorefineries.

Workshop participants were selected from widely known and respected experts in diverse segments of industry, academia, and government. Individual workshops were held in St. Louis, Missouri, on December 3, 2009, and in Chicago, Illinois, on December 10 and 11, 2009.

This report summarizes the workshop discussions.

[a] *Perlack RD, LL Wright, AF Turhollow, RL Graham, BJ Stokes, DC Erbach (2005) Biomass as a feedstock for a bioenergy and bioproducts industry: the technical feasibility of a billion-ton annual supply, DOE/GO-102005-2135.*

The *High-Yield Scenario Workshop Series Report and Executive Summary were* prepared for the U.S. DOE/EERE Biomass Program, by Idaho National Laboratory (INL).

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Documents can be accessed at www.inl.gov/bioenergy/hys

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U.S. Department of Energy – Energy Efficiency & Renewable Energy
INL/EXT-10-20074

Billion-Ton Study Update "High-Yield Scenario" Workshop Series

SUMMARY REPORT

Workshop *1 – Corn/Agricultural Crop Residues*
December 3, 2009 ▪ St Louis, MO

Workshop 2 – Herbaceous Energy Crops
December 10, 2009 ▪ Chicago, IL

Workshop 3 – Woody Energy Crops
December 11, 2009 ▪ Chicago, IL

Prepared by
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SUMMARY

The "High-Yield Scenario" workshop series was sponsored by the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy (DOE/EERE) Biomass Program to identify and discuss the challenges associated with substantially increasing production of lignocellulosic biomass resources, such as agricultural crop residues (in particular, corn stover) and herbaceous and woody energy crops, to sustainably supply feedstock for biorefineries. Workshop participants were selected from widely known and respected experts in diverse segments of industry, academia, and government. Individual workshops were held in St. Louis, Missouri, on December 3, 2009, and in Chicago, Illinois, on December 10 and 11, 2009. This report documents the discussions and findings of those workshops.

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INTRODUCTION

Exploring the Technical Feasibility of High-Yield Biomass Production

Developing a sustainable cellulosic bioenergy industry capable of meaningfully offsetting fossil fuel consumption presents a number of challenges for current production systems. While existing systems are effective at meeting present demands for food, feed, and fiber, the amount of biomass needed to support a bioenergy industry will require more efficient use of existing systems and development and implementation of new systems and practices to achieve significantly higher levels of biomass production than current baselines. The challenge requires several approaches, which include increasing crop yield and improving production and supply chain efficiencies.

The potential to increase yields of cellulosic biomass continues to be debated. This discussion can be divided into two realms: (1) the maximum yield potential technically possible through crop development and management advances, and (2) external influences (i.e., environmental sustainability requirements, land-use change, economics/markets, and policy) that will impact the amount of resource actually available for bioenergy production. Both lines of discussion are important for reliably estimating biomass resource potential, but without an understanding of the former, the influences of the latter cannot be modeled.

"High-Yield Scenario" Workshop Series

To get a sense of the potential impact of research and development (R&D) on biomass resource availability, and to evaluate the feasibility of yields higher than baseline assumptions used for past assessments, an alternate "High-Yield Scenario" (HYS) concept was presented to industry experts at a series of workshops held in December 2009. The workshops explored potential future production of corn/agricultural crop residues, herbaceous energy crops (HECs), and woody energy crops (WECs).

The workshop objectives were as follows:

1. Develop alternate assumptions for bioenergy feedstock assessment analyses beyond current baseline assumptions (factoring in potential improvements in crop yield and management strategies)
2. Validate alternate assumptions with scientific experts and gather industry, academic, and government support for a HYS resource assessment
3. Discuss potential future research initiatives that might support these assumptions.

Three workshops were conducted with invited experts from industry, academia, and government to validate the alternate assumptions and outline science and technology advances needed to achieve these new targets. The workshops were organized by type of biomass resource: *Workshop 1 – Corn and Agricultural Crop Residues, Workshop 2 – Herbaceous Energy Crops,* and *Workshop 3 – Woody Energy Crops.*

Workshop participants were asked to identify and consider issues that enable or constrain higher yields, providing referenceable justification wherever possible, and project future yield potential that could be achieved as advancements in technology and management strategies currently on the horizon are implemented and barriers addressed.

Workshop-specific baselines, projections, technical barriers, and promising advances are included in this document. This report also includes detail about participants' and observers' workshop input regarding specific energy crop development issues and external influences (i.e., environmental sustainability requirements, land-use change, economics/markets, and policy) that will impact the total quantity of cellulosic biomass resource available for bioenergy production.

Representation of Industry Expert Opinion

Widely known and respected experts were selected from diverse segments of industry, academia, and government. To assure the discussions explored each workshop topic systemically, participant panels included experts ranging from crop/plant breeders and geneticists to equipment manufacturers, specialists in environmental sustainability and economic viability, and feedstock producers.

The participants' diversity of expertise allowed workshop sponsors to assess the breadth of related issues that support or constrain efforts toward increased feedstock yields. This diversity also presented challenges for reaching coordinated consensus among participants when they were asked to estimate future yield potential and other specific yield-related values.

Workshop participant input is discussed in terms of trends and is intended to illustrate the variety of expert opinion that currently exists, provide some context for those opinions, and provide some industry-informed justification for model inputs for a HYS resource assessment case study.

Participants do not necessarily support all opinions appearing in the executive summary or this report, but their input is included within the ranges presented. Wherever possible, the full report references actual participant input (anonymously), including literature recommendations (see Notes and References section at the end of each workshop summary in this report).

Assumptions Regarding Yield Improvement Projections

Participant discussions focused on identifying the crop and management developments needed and those most likely to be realized to produce a step-change in currently projected yield improvement rates. In many cases, the likelihood of these improvements being achieved depends on external influences including environmental sustainability requirements, land-use change, economics/markets, and policy. Participants were asked to make projections under the assumption that these external factors are favorable to support a HYS.

Workshop Format

Facilitated Discussion

The workshop discussions were organized according to their relative impact on feedstock availability. Major assumptions used to estimate the availability, sustainability, and economic impact of biomass feedstocks were prioritized highest to lowest, as shown in Table I-1.

Table I-1. Workshop assumption discussion topics.

HYS Discussion Topics
1. Yield Potential
2. Environmental Sustainability
3. Economic Viability
4. Land Use
5. Other Technology/Policy Advances

Each Assumption Discussion was organized in the general discussion structure shown in Table I-2. Discussion prompts and questions were provided as a catalyst for the assumption enablers.

Table I-2. General discussion structure.

Workshop Discussion Structure
1. Present the Alternate HYS Assumption
2. Identify the related limiting factors that define current baseline projections
3. Discuss HYS assumption enablers
4. Formulate a list of likely advances that could support an alternate HYS assessment

Participants were asked to discuss the likely advances they were knowledgeable about that address limitations inherent in current baseline projections for bioenergy feedstock supply systems. Participants were invited to provide input from their expert perspectives regarding these assumptions, including projection data and justification for their projections.

The workshop discussions identified barriers to achieving the Alternate HYS Assumption, adding or subtracting as appropriate, and then identified potential scientific or technical advances, or solutions, that might bring them to fruition. Approximate timeframes for implementation of those advances were then projected for the near term (2017), midterm (2022), and long term (2030). Projections were also made for 2050 to help develop research initiatives.

Information was captured in a variety of ways throughout the workshops, including (1) an idea/discussion management software tool, (2) facilitator-captured input of discussion, and (3) electronic files or hard copies provided by participants. The discussion prompts and questions were addressed indirectly through open discussion of the topics, and participants were encouraged to include related question numbers with qualitative information they entered into the idea/discussion management tool. If exact projections were proprietary information, participants were encouraged to project a range rather than a specific value. The idea/discussion management tool allowed input to be anonymous as well, so others in attendance did not know who authored what information.

Idea/Discussion Management

Ideas discussed and information presented were captured using computer-assisted facilitation with Group Systems Meeting Room© software. This tool increased discussion efficiency by enabling simultaneous digital capture of participant information and then rapid categorization, ranking, and calculation capabilities. Each participant had access to a computer that was linked with other computers in the room. Information entered by the recorder or participants appeared on a projected screen that was visible to participants and observers. Ranking or scoring of information was performed via the computers, and the results were immediately available for review and discussion. Participants' input of data and scoring was anonymous. Participant-chosen screen names were recorded with participant comments, but these were not visible at the workshop. For each workshop, an integrated workshop record was produced that included the discussion guides, participant input, and information captured by the facilitator and recorder.

Excerpts from these records are included in the Notes and References section at the end of each workshop summary in this report.

Workshop Findings

The task put before participants was challenging—to inventory issues that enable or constrain higher yields, to provide referenceable justification wherever possible, and to make estimates for future yield potential based on each participant's expert knowledge of crop species development, markets, policies, and other related issues of impact. There was not always time to explore these issues thoroughly, and workshop sponsors acknowledge that these are important and complex topics that will be explored in greater depth as research goes forth.

> **WORKSHOP FINDINGS**
>
> For each category of biomass resource, experts from diverse backgrounds were optimistic that sufficient yield improvement could be achieved by 2030 to support a High Yield Scenario (HYS).
>
> Yield improvements are needed for all crops; no single crop can do it alone.

The purpose of the "High-Yield Scenario" workshop series was to determine if industry experts believed that likely innovations in technology and management strategies could enable higher yields than current USDA baselines project, and, if so, what those yields might be. Baseline estimations were discussed and agreed upon for each workshop (see Workshop Summary Sections 1, 2, and 3 for details about how baselines were established).

Participants' projections span greater breadth as time progresses, which is a reasonable representation of the impact of diverse expert opinions over time based on their optimism that the necessary advances will occur and will produce the predicted outcome. The more conservative projections communicate the very real risks that the limiting factors discussed in these workshops pose to achieving the HYS. The more optimistic projections communicate that some experts believe, based on promising advancements they are aware of, these risks can be addressed, and significantly greater yields can be realized sustainably.

Figures I-1, I-2, and I-3 summarize participants' projections. Greater detail on crop, region, and crop-specific limiting factors and assumption enablers are discussed in each workshop section of this report.

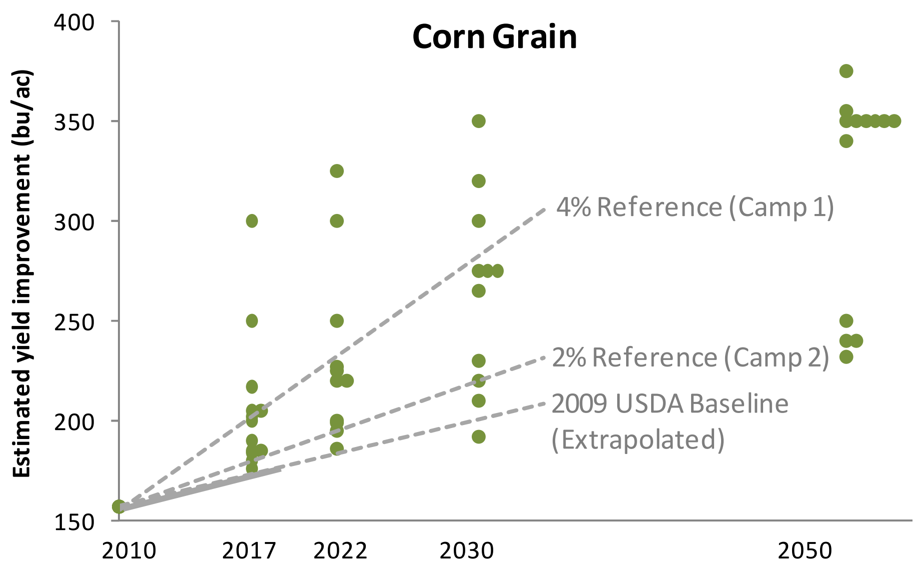

Figure I-1. Projections for future corn grain yield fell into two camps: Camp 1 estimates the HYS is achievable by 2030 and Camp 2 believes it could be achieved around 2050 or later.

For HECs and WECs, crop production was estimated according to the land resource regions shown in Figure I-2.

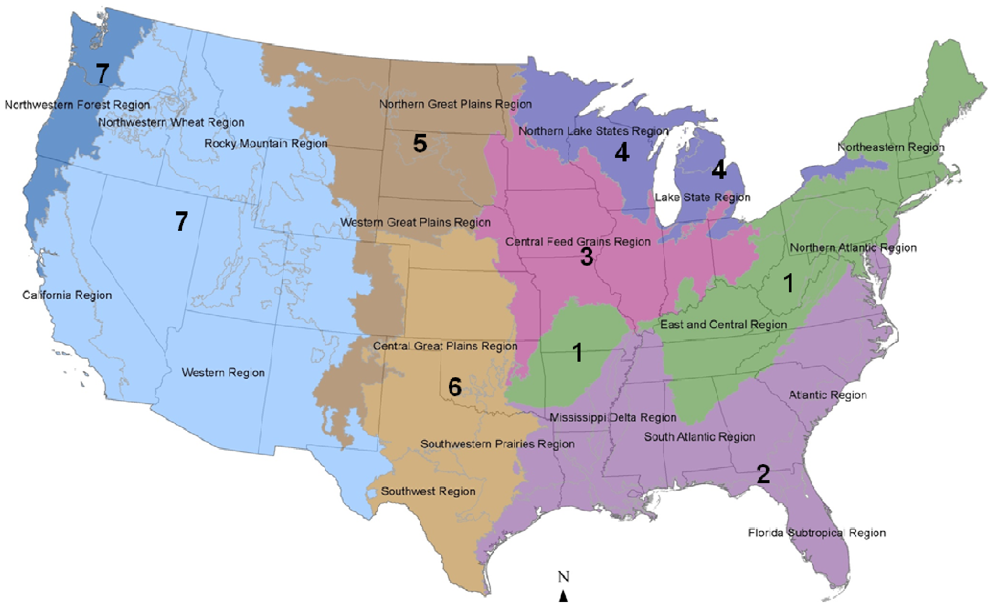

Figure I-2. Land resource regions used to estimate current yields of HECs and WECs (adapted from USDA-NRCS [2006]).[a]

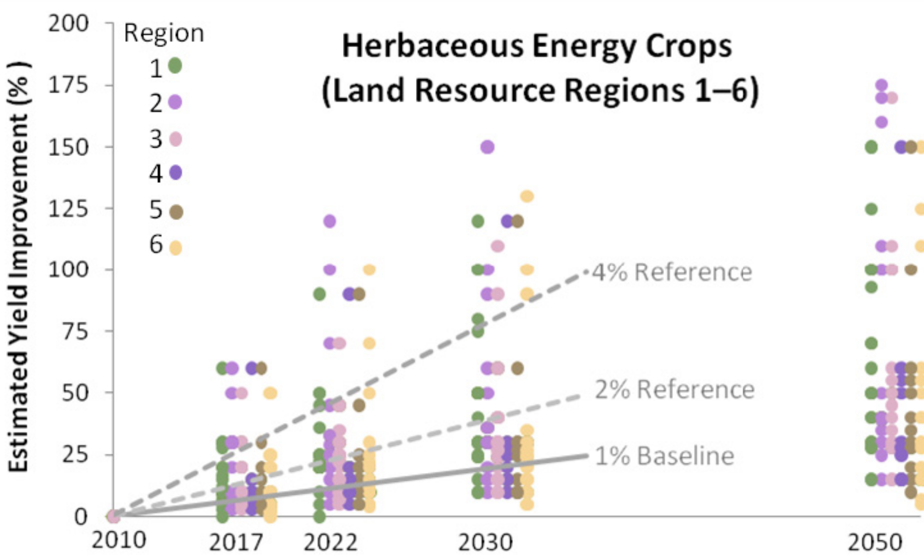

Figure I-3. The greatest density of projections for HECs, collectively, occurs at improvement rates between ~0.5and 3% in the near term, and there is optimism for some species to experience even greater rates of improvement in some regions. Optimism for rapid increase of rate improvement (2% and greater) was projected in Regions 1, 2, 3, and 6.

a. USDA-NRCS (2006) Land Resource Regions and Major Land Resource Areas of the United States, the Caribbean, and the Pacific Rim, USDA Agriculture Handbook 296.

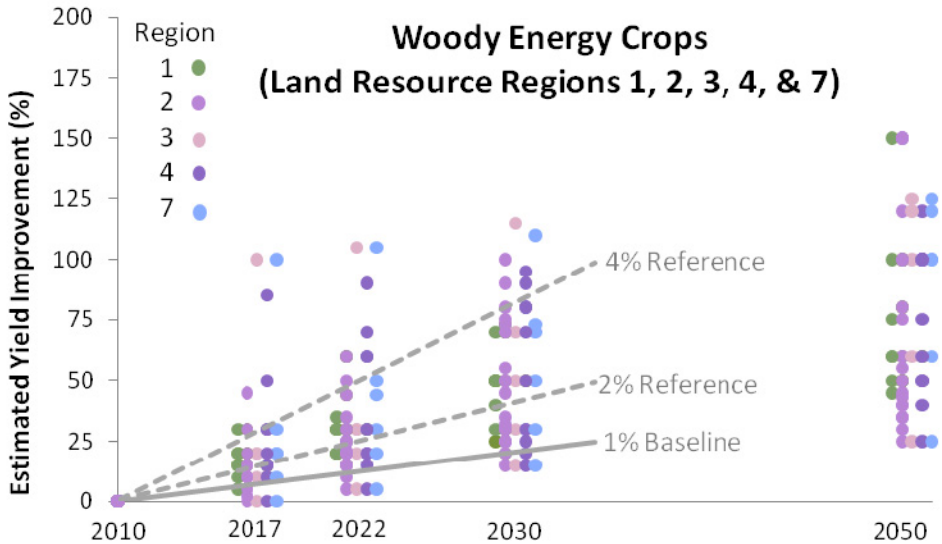

Figure I-4. The greatest density of projections for WECs, collectively, occurs at improvement rates between ~1 and 4% in the near term, and there is optimism for some species to experience even greater rates of improvement in some regions. Optimism for rapid increase of rate improvement (2% and greater) was projected in Regions 1, 2, 4, and 7.

Figures I-3 and I-4 illustrate that industry experts believe that HECs and WECs produced using the most appropriate varieties in the most appropriate growing regions are technically capable of achieving greater than a 1% baseline yield improvement, and are likely to do so as policies and markets drive advancements in crop development and management practices.

WORKSHOP 1 – CORN/AGRICULTURAL CROP RESIDUES

Workshop Participants[a]*: Steven C. Barr, Michael D. Edgerton, Douglas Haefele, Larry Hasheider, Douglas Karlen, Kendall, Lamkey, David Loos, Todd Mathisen, Todd Peterson, Raymond Riley, Michael C. Roth, Lee Stromberg*

Defining the Resource and Estimating Yield Baselines

"Corn/Agricultural Crop Residues"

The largest agricultural source of biomass for bioenergy development is estimated to come from annual crop residues (Perlack et al. 2005). Of the 1.3 billion dry tons of biomass resource that the United States is estimated to be capable of producing annually within 35 to 40 years,[b] Perlack et al. (2005) estimated 446 million dry tons would come from annual agricultural crop residues. Since that assessment, the amount of crop residues potentially available has been reconsidered to accommodate the amount of biomass that needs to remain in the field to maintain soil productivity.

For example, corn (*Zea mays*) stover resources (the stalks, leaves, and cobs that remain after the corn grain is harvested [Figure 1-1]) currently provide 75% of total annual crop residues available for biofuel production (Nelson 2002), with approximately 5.1 million acres (mostly in the Midwestern states region) producing an estimated 180 million tons of total residue (USDA-NASS 2008). Existing residue collection technology efficiencies (Patterson 2003; Hess et al. 2006; Shinners and Binversie 2007) often exceed the amount of stover that can be removed while maintaining soil organic carbon and plant nutrients and preventing erosion, excessive soil compaction, and other environmental degradation (Johnson et al. 2006; Wilhelm et al. 2004; Nelson 2002; Sheehan et al. 2004), and foreseeable single-pass harvest technologies will be capable of even greater residue removal (Shinners et al. 2007).

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a. Workshop participants contributed the content of the report through survey answers and in-workshop comments. Individual participants are responsible for only the opinions and data they provided. Workshop report editors are responsible for assimilation of workshop data and participant comments in this summary.

b. In addition to meeting food, feed, fiber, and export demands and with technology advancements, adapted tillage practices, and carefully orchestrated land-use change (Perlack et al. 2005).

Figure 1-1. Idaho National Laboratory (INL) stover harvest trial in Ames, Iowa, October 2006.

Corn/Agricultural Crop Baseline Yields

Sufficient historical data exists for the U.S. Department of Agriculture (USDA)[1] to publish and regularly update projections for future corn grain production, which, in turn, can be used to project future stover residue production. Baselines extrapolated from USDA projections available at the time of the workshops are shown in Table 1-1. Figure 1-2 shows graphically the average 2009 corn grain yield distributed by county.

Table 1-1. Extrapolated USDA baseline projections for corn grain production for three future time periods (based on 2009 yield data).[1]

	2009	2017	2022	2030
Corn yield (bu/ac)	157	174*	183*	201*

**2017 data based on USDA 10-year baseline projections. 2022 and 2030 are straight extrapolation from baseline.*

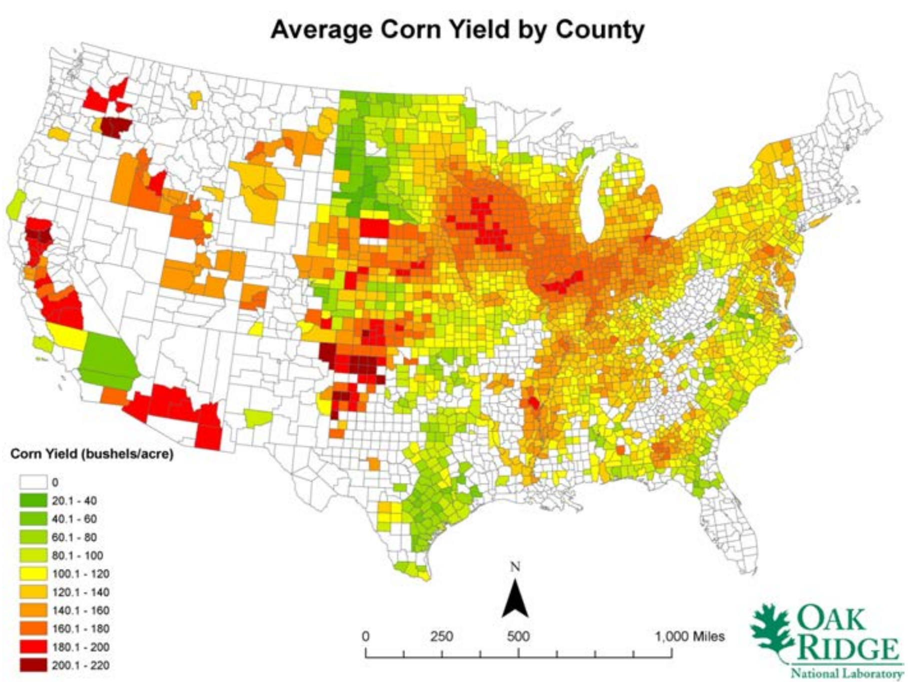

Figure 1-2. Average 2009 corn yield distributed by county.[1]

Alternate HYS Assumption Discussions

Workshop participants discussed R&D currently underway to improve corn grain yields beyond current baselines (extrapolated from 2009 USDA 10-year projections [Table 1-1]). They also discussed the extent that they believe future production improvements may be realized to support a HYS biomass resource assessment. The discussions were framed within the alternate assumptions shown in Table 1-2 and are summarized in Sections 1.1 through 1.5.

Table 1-2. Workshop 1 – Corn/Agricultural Crop Residues alternate HYS assumptions.

Discussion	Alternate Assumption
Corn Grain Yield	Average corn grain yields will increase beyond current extrapolated baseline (based on 2009 USDA 10-year projections[1])
Environmental Sustainability	The rate of adoption of currently practiced environmentally conscious managements will exceed projections, and innovative new strategies will emerge, both leading to increased stover removal rates
Economic Viability	Economic conditions are met that incentivize producers to manage and sell residues
Land Use	Land-use change is based on net returns resulting from landscape-scale management of multiple products, including ecosystem services, to ensure sustainability (i.e., land is used according to its best value)
Other Technology/ Policy Advances	Other technologies, research initiatives, and policies that will impact future corn residue availability are identified.

1.1 Alternate HYS Assumption – Yield

Average corn yields will increase beyond current extrapolated USDA baseline projections (based on 2009 USDA 10-year projections[1]).

The objectives of the first alternate assumption discussion were to (1) identify the issues constraining and supporting a HYS and (2) project potential future yield improvements that are technically possible if promising crop development and management advances currently on the horizon are realized; thus, market drivers, impacts, and other economic reactions were separated out of the yield potential discussion. Participants explored the alternate assumption through facilitated discussion of two topic areas: Future Grain Yield and Impacts to Harvest Index. Economic issues impacting the biomass industry at various points were explored in a later discussion session.

Limiting Factors

Participants first identified a number of technical barriers, or "limiting factors," constraining yield. These were ranked from greatest to least impact in constraining or supporting increased yields.

Factors that impact the HYS (ranked in order of greatest to least impact)

1. Tolerance to drought, pest, and other stress factors that increase yield variability
2. Genetics
3. Changing global weather patterns
4. Nutrient-use efficiency
5. Soil productivity
6. Changing pest spectrum
7. Rate of return on investment
8. Physiological limitations of higher plant densities
9. Rotation crop selection
10. Nutrient variability
11. Government policy as it relates to corn demand
12. Technology provider to be able to capture economic return
13. Landscape-scale management
14. Technology acceptance
15. Other

1. Tolerance to drought, pest, and other stress factors that increase yield variability

Much of the variability in yield has been reduced by recent improvements in modern agronomics through the application of breeding and biotechnology applications (engineered pest resistance) as well as improvement in equipment.[2] One of the greatest barriers to implementing the HYS is variability in producer management systems and experience.[3]

Tolerance to drought, pest, climate change, and other stress factors represent barriers to plant biomass productivity that participants expected to constrain yield potential. Climate changes that increase average temperature are likely to increase pest, weed, and disease pressure.[4,5] Increased irrigation demand resulting from climate changes and increasing the total production area will, in turn, impact water resources.[6]

Resistance genes to two major insect pests, the corn root worm (CRW) and the European corn borer (ECB) successfully incorporated into corn hybrids have made a significant contribution to yields.[7] However, a major increase in yield improvement by adding resistance genes for controlling other insects is not expected to have as great of an impact, unless the genes controlling CRW and ECB lose their effectiveness.[8] However, as resistance to these insect toxins evolves and/or new insect pests move into the previously occupied niches, better management of these and identification and application of toxin genes for evolving resistance of new pests may be needed just to maintain yields. New fungal and drought resistance that exploits genetic diversity in combination with the use of genetic markers will likely assist in more rapid selection of fungal resistance as well as for drought resistance and result in higher yields.[5]

2. Genetics

Molecular plant breeding has made a major impact on high corn yields, but hybrid yield potential may be reaching its theoretical limits. If so, this is a barrier to future yields. Corn hybrids have continued to dramatically improve, but some participants believed that grain yields from hybrids selected just a few years ago plateaued at 240–250 bu ac^{-1}. Other participants pointed out that newly selected hybrids produced more than 300 bu ac^{-1} in 2009.[9] Participants also indicated that to satisfy customers, stover yields must not overtake relative grain yields. Grain yield is the current market driver. The drive toward an increasing grain harvest index is in conflict with breeding programs that would simultaneously select for both higher biomass and grain yield. Today's seed customers are demanding more grain and less biomass, so selecting for both requires a paradigm shift. This change would require a longer commitment to increasing stover value. The genetic potential for the improvement of corn stover hybrids is based on the variation found in hybrid stover sugar content and conversion recalcitrance. Improving stover value by selecting for higher feedstock quality and for improved processing attributes could increase its value and may help offset some of the concern regarding the perceived tradeoff between the selection of higher biomass yields at the expense of grain yields.

3. Changing global weather patterns

Changes in local and global weather patterns were considered a potential barrier to increased yields. Weather (rainfall, heat) is the most significant factor impacting annual grain yield. Weather can easily have a 2x factor on yield, ranging from 100 bu ac^{-1} to 200 bu ac^{-1} on the same field with the same hybrid in two consecutive years.[10] In the United States, warmer temperatures are likely to increase pest, weed, and disease pressure and also night time respiration rates.[4] Weather patterns have a large effect on economics/crop prices and need to be explicitly considered in longer term supply models. Adaptation due to selection for heat and pest resistant corn hybrids may offset the effects of climate change to some extent. Breeding programs are continually selecting new hybrids in their target markets. Unlike most other crops, corn germplasm has a rapid turnover rate, with an average hybrid having a sales half life of about 4 years. However, because the impact of temperature trends over time is difficult to predict, improved models are needed to help better manage the impact of weather and water resources on yields.[11]

4. Nutrient-use efficiency

The cost in nutrients (NPK) due to natural gas prices, green house gases (GHG), or water quality legislation is a barrier to increased yields and could slow the annual rate at which plant productivity could increase. As yields continue to increase, crop nutrient needs become more critical. For example, micronutrients may not be limiting at 200 bu ac^{-1}, but they may limit yields at 300 bu ac^{-1}.[12] Another limiting factor that nutrient costs can create is that as fertilizer prices increase, farmers may apply less to increase net farm income, which ultimately reduces yield.[13] This may be offset to some extent through the indirect selection of corn hybrids with lower grain protein levels, a trend that has been underway for several years.

Nutrient-use efficiency constraints include more than just fertilizer-use. Limiting factors to address for total nutrient-use efficiency also include nutrient cycling within the soil system.[14]

5. Soil productivity

The current soil type characterization system may not be as helpful as needed for accurately predicting potential corn yield. Current soil maps are only very rough estimates of the actual soil that is present.[15] To overcome this barrier, an index needs to be developed that better describes a spatial estimate of the size of the "sponge" under each plant.[16] In addition, projections must account for spatial variability at least at the section level (640 ac), as there are parts of each field where no residue can or should be removed and other parts where as much as 80% might be safely removed without impacting sustainability.[17] If good soil and slope-based yield predictions are developed, this may support the adoption of variable rate seeding and location-specific hybrid recommendations. In other words, this knowledge could contribute to increased corn yields.

6. Changing pest spectrum

A barrier to high yields is the need to continuously respond the changing spectrum of crop diseases and evolving pathogens.[18]

7. Rate of return on investment

A barrier to the development and acceptance of biomass as a valuable farm commodity depends on the perceived return on investment for producers and companies developing new hybrids. The combination of harvesting both grain and biomass as cash crops could lead to increased farm revenues.[19] Unless producers receive a high enough return through the increased demand for corn and biomass, they will not invest in purchasing the new biotech technologies.[20] The price of purchasing and managing new hybrids and the producers' return on investment is ultimately influenced by the biotechnology research investment.[21] In addition, higher new hybrid technology costs and energy costs associated with fertilizer application, tillage, transportation, and grain drying all impact crop management priorities.[22] Finding an appropriate pricing strategy for the biomass is of utmost importance to the viability of biomass collection.[23]

8. Physiological limitations of higher plant densities

Physiological limitations of higher plant densities pose another barrier to continued increases in yield associated with increasing densities. Even though increased yields are highly correlated to increased plant density, it is unclear to what extent increasing plant densities can continue to impact yields.[24] Producers' response to changing weather influences may constrain the HYS. For example, during the 2009 production season, central Iowa received much lower than average heat units, and there was no yield difference between 32,000 and 44,000 plant population.[25] With no yield difference at the higher density, and with the cost of 32,000 plants per acre being much less than the cost for 44,000, a producer's return on investment will be greater under limited heat unit growth conditions.[26]

9. Rotation crop selection

Rotation crop selection can be a barrier, and its management is important to maximizing yields.[27,28,29]

10. Nutrient variability

Nutrient variability is another barrier that depends on spatial differences in availability. Similar to the soil type discussion above, better understanding of nutrient needs and placement could improve yields and reduce grower costs. This needs to be considered from a nutrient supply perspective and depends on crop/soil interactions.[30] Nitrogen fixation could be an important contributor to the HYS management system.[31]

11. Government policy as it relates to corn demand

Government policy as it relates to corn demand can be either a market driver or a barrier to the development of crops for biomass feedstock production. Government policy has had a high impact on the drive for higher yields.[32] Mandatory demand for cellulosic feedstocks could drive increased stover yields and slow increase of corn grain yields.[33] Blending rules are limiting demand.[34] EPA regulations regarding herbicides like Atrazine and others could reduce corn yields.[35]

12. Technology provider to be able to capture economic return

Technology providers must to be able to capture economic return on improved hybrids that produce higher biomass yields; however, because hybrid development has been focused primarily on increased grain yields, biotechnology solutions that could increase biomass are, for the most part, being "shelved."[36] This lack of ability to capture biomass improvement value is a major barrier to realizing the HYS.[37]

13. Landscape-scale management

Landscapes vary and are controlled by biological processes. Traditionally, corn has been grown as a monoculture. However, a more diverse set of crops may better balance the competing needs for yield (productivity), carbon sequestration, water quality, biodiversity, wildlife, and community development at the landscape scale to advance overall yields.[38] This may actually lead to an increase in average corn yield if corn is preferentially grown on flatter, more productive ground and perennial species are grown on ground with higher erosion potential.

14. Technology acceptance

Technology acceptance depends on producer and technology provider ROI as well as societal tolerance of GMO traits, i.e., global grain flow acceptance.[39]

15. Other

Two other barriers to the development and implementation of the HYS for corn include the lack of solid technical understanding of the relationship of stover collection methods and actual harvest index (HI) ratio of stover to corn[40,41] and how residue removal effects nutrients, soil water parameters, and erosion, as well as water-use efficiency and competition for water resources will constrain producer participation.

Assumption Enablers

The limiting factors were projected on a screen to use as a guide to brainstorm solutions, or "assumption enablers," that might support increased yields and the HYS assessment. Ideas were organized and ranked according to their potential to impact biomass yields. A broad range of promising approaches and needed advancements were suggested that fall under a number of different R&D and policy arenas. For convenience, these are summarized in this section under three categories: Yield Genes, Stress-Resistance Genes and Agronomic Management.

Participants suggested that plant breeding, genetics, and biotechnology programs can more fully exploit (1) "yield genes" to produce the maximum yield that a crop could achieve "at a very favorable confluence of genotype, management, radiation, and temperature" and (2) "stress-resistance genes" that enable sustained yield increases in a variety of less favorable growing environments.[42] Genetic selection of superior varieties simultaneously employing conventional and biotechnology, molecular breeding methods was the number one identified potential solution.

Yield Genes

While much development has already occurred for the corn species, the focus of this development has centered on improvements to support grain production. Sixty years of corn breeding programs continued to improve corn yields until well into the 1980s, and since then the rate of increase has slowed, suggesting that a large portion of the yield potential for corn grain may already have been accomplished. number of participants were optimistic that there is still room for stover yield improvements within the species potential of corn and recommended continued work in genetics, including selective breeding and the application of new biotechnology approaches.[43,44,45,46] However, other participants stressed that without a market pull for higher stover yields relative to grain yields, the emphasis will continue to be on maximizing grain yields.

Stress-Resistance Genes

Much of the remaining genetic development potential for corn involves improving plant tolerance to stressors. Participants expect yield increases as a result of reducing variability in corn yield and selecting hybrids that push the physiological limits of drought[47,48] and higher plant densities.[49,50,51] Participants pointed out examples that demonstrate how the application of biotechnology can successfully improve plant tolerance to stressors and solve problems, such as the solution developed for infestation by corn root worm (CRW) and the European corn borer (ECB), two of corn's biggest insect pests.[52] Resistance to fungal disease is also expected to improve yields with the exploitation of genetic diversity and the continued application of molecular plant breeding. [53]

Agronomic Management

Agronomic Management captures suggestions for reducing variations in yield that result from plant stresses encountered as the cultivar interacts with conditions in various environments. There may be significant potential for yield gains through innovations in management to produce the best growing conditions possible for the species, growing region, and land class. One participant noted that in high-yield contests, where everyone has access to the same seed varieties, yield still varies, suggesting that "the major difference between average yields and yield contest yields is management."[54,55,56] Innovative tillage and other soil management practices, including validation of, development of BMPs, and extension will support the high-yield scenario.

When asked what the next breakthroughs would be that produced a change in the slope curve, a number of participants suggested breakthroughs would be achieved with technologies that address producers' ability to understand their growing environment better and more accurately predict changes occurring in the environment, such as new applications using global positioning systems, computerized planting, real-time monitoring (i.e., spectral imaging and remote sensing) to understand what it occurring in the field.[57,58,59,60,61]

Projecting Future Grain Yield Improvement

Participants then made projections, based on their expert opinion and the facilitated discussion, about the potential for grain yield increases if limiting factors are overcome and likely advances are implemented.

Analysis of workshop data and information gathered identified trends, or "opinion camps," apparent within each topic. The trend characterization provided in this analysis references workshop comments and literature. Figure 1-4 shows frequency distribution in participants' responses for estimates of potential corn yield.

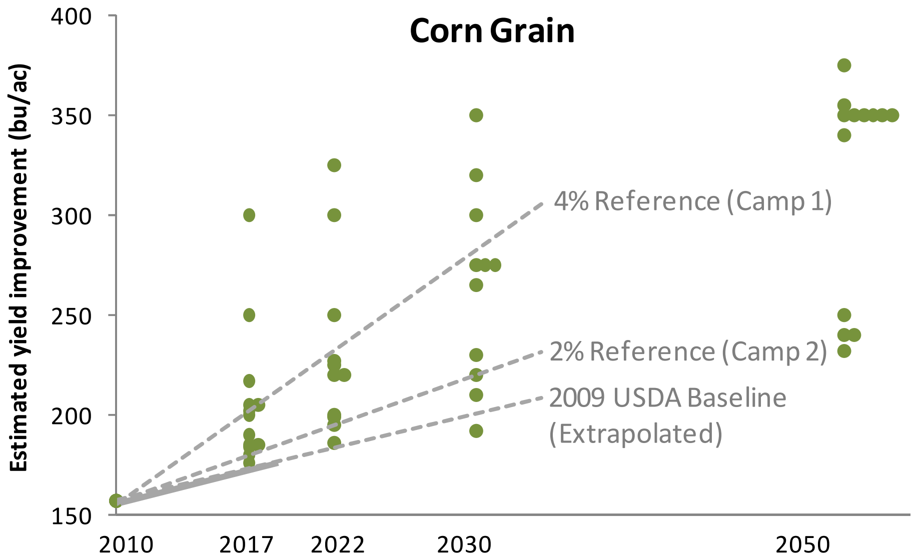

Figure 1-4. Projections for future corn grain yield fell into two camps: Camp 1 estimates the HYS is achievable by 2030, and Camp 2 believes it could be achieved around 2050 or later.

The participants demonstrated clear agreement on continued growth of corn yields through 2050. The key divergence in opinions was centered around the extent to which breeding and genetic selection programs can overcome stress factors. Participants expressed a consensus opinion that corn yields would increase toward a genetic potential that achieves a HYS, but demonstrated differences in opinion on the timeframes required to achieve the HYS.

Figure 1-4 shows that a majority of participants (Camp 1) believed that genetic development and advanced management concepts would produce a near-term step change in annual yield increase (~4% or greater) and enable grain yields approaching 250 bu/acre by 2030.

Camp 1 participants' discussion and comments reflected a consensus opinion on the genetic potential of corn existing to achieve the HYS. Literature suggested by a participant reports documented yields of up to 360–370 bu/acre using seed hybrids available today and points out that 7 of the 27 corn yield contest winners in 2006 produced yields over 300 bu/acre.[62] This suggests that there is genetic potential for achieving the HYS. Comments submitted also indicated that increased yield rates from new hybrids are on the horizon, with the first hybrid products from molecular breeding programs now becoming commercially available. One participant reported very high yield levels using hybrids released just a few years ago (240–250 bu/acre) and 300+ bu/acre with their newest genotypes.[9] Additional yield increases are also expected as a result of reducing variability in corn yield and selecting hybrids that push the physiological limits of higher plant densities.[63,64] Participant comments reflected that yield increases are supported by one of corn breeders' continuing objectives, which is to select plants that tolerate higher and higher plant densities.[65]

The remaining participants (Camp 2) believed that advancements would continue at a rate more consistent with past yield improvement, and that it would be 2050 or later before HYS yields would be achieved (nearer to 2% annual increase and the USDA baseline). Participants ranked tolerance to drought, pest, disease, and other stress factors[66,67] as the greatest barrier to increasing yields at a pace required to achieve the HYS by 2050.

Opinion Camps Emerging on the Ability to Overcome Stress Barriers

The most significant variance in opinions was focused on the ability to overcome barriers associated with environmental stresses. The more aggressive yield projections of Camp 1 represent the position that HYS-supporting solutions will come from genetic selection of superior varieties implemented in tandem with innovations in conventional and biotechnology-enhanced molecular breeding methods.[65,68,69] Participants pointed out examples that demonstrate how the application of biotechnology can successfully solve problems, such as the solution developed for infestation by corn root worm (CRW) and the European corn borer (ECB), two of corn's biggest insect pests.[70] Participant comments indicated that management of insect pests with selective toxins is expected to continue as new pests enter into the niche formerly occupied by the CRW and ECB or as these pests' resistance evolves.[71] Resistance to fungal disease is also expected to improve yields with the exploitation of genetic diversity and the continued application of molecular plant breeding.[69] While acknowledging the evidence of 300+ bu/acre yields in yield contests, and increasing ability to overcome stresses, the more conservative yield projections of Camp 2 represent the position that environmental constraints would limit the average yields across the entire landscape from reaching the HYS.

Projecting Impacts to Harvest Index

Participant discussion and opinions relative to harvest index (HI) mirrored the challenges and complexities associated with HI determination across the industrial and research communities. Three primary conceptual themes emerged upon review of workshop presentations, participant comments, and supporting literature. A group of participants with considerable experience looking at HI provided a data-driven case that HI at harvest time is currently increasing with higher grain yields and genetic selection.[72,73] There was also a broad group of participants that clearly, and collectively, stated that HI can be a breeding and selection characteristic for HYS production systems.[74,75,76,77,78,79] Another group of participants represent the position that while harvest-time HI is demonstrably increasing with yield under current production, the HI at physiological maturity is a more important criterion for determining sustainable HYS stover availability.[80] This concept, with supporting literature,[81] presents the case that the environmental processes determining available stover must utilize a complete system material balance, which is most accurately represented by HI at physiological maturity.[82]

The conclusions of the participant discussion essentially became (1) harvest time HIs are increasing as yield increases, (2) the material balance calculations needed for accurate stover availability analysis require HI at physiological maturity, for which less data exists to construct HI trend analysis, and (3) HI is a crop characteristic that can be engineered to serve market drivers as they emerge and change in a HYS. Subsequently, a strict determination of HI trends as the HYS emerges is challenging, and analysis assumptions for the HYS resource base should focus on absolute

Regarding future impacts of the HYS to Harvest Index (HI), three primary concepts emerged upon review of workshop presentations, participant comments, and supporting literature:

1. Harvest time HIs increase as grain yield increases
2. The material balance calculations needed for accurate stover availability analysis require HI at physiological maturity, for which less data exists to construct HI trend analysis
3. HI is a crop characteristic that can be engineered to serve market drivers as they emerge and change in a HYS.

potential. These conclusions, and participants who identified them, are not mutually exclusive, but as presented in the following discussion, the distribution of comment and discussion points correlate with these three concepts.

A critical first step in facilitating a discussion of HI is defining the mathematical representation. By definition, HI is the ratio of grain mass to total plant mass (above ground biomass), i.e., HI = 0.5 for a corn plant where grain mass and plant mass are equal. HI is also often analyzed as the ratio of aboveground plant mass (other than grain) to total grain mass. In this scenario the HI = 1 for a corn plant where grain mass and plant mass are equal. This remains a significant communication gap for HI discussions, and the data contributed by the participants demonstrates each of these two perspectives, and in some cases has required recalculation into the chosen HI methodology for this report: HI = $mass_{grain}$ / $mass_{abovegroundbiomass}$. Conversions between reporting methods are calculated as follows:

$$HI_1 = \frac{1}{HI_2 + 1}$$

$$HI_2 = \frac{1}{HI_1} - 1$$

where,

$$HI_1 = mass_{grain}/mass_{total\ above\ ground\ biomass}$$

$$HI_2 = mass_{above\ ground\ biomass\ other\ than\ grain}/mass_{grain}$$

Participant Conclusion 1: Harvest time HIs increase as grain yield increases

Substantial data was presented from current work that shows increasing HI at harvest time with increasing yield. The case for a continuation of this trend was presented emphatically, referring to the significant dataset from ongoing projects. Within the group of participants citing HI increases, the endpoint HI in 2050 was spread across a wide range, with a maximum projected HI of 0.71, and minimum projected HI of 0.54. This range of projected 2050 HIs has a potentially substantial impact on the quantity of stover available for collection.

Participant Conclusion 2: The material balance calculations needed for accurate stover availability analysis require HI at physiological maturity, for which less data exists to construct HI trend analysis

Participants primarily discussed HI as a harvest time measurement. This is a significant assumption considering the difference between HI at physiological maturity and harvest time has potentially vast impacts on the HYS analysis. Harvest time measurements are a standard when considering HI for several reasons. First, more often than not, the primary interest in understanding HI is quantifying the harvestable material available. Thus, material losses between physiological maturity and harvest time aren't considered harvestable. Another reason the HI discussion focuses on harvest time is the ability to perform better and more comprehensive measurements. At physiological maturity, the quantity of measurable biomass is at or near its maximum level. When investigating HYS biomass availability it is important to account for all biomass material that enters the system. Material lost between physiological maturity and harvest operations, while not harvestable, is still potentially available for soil maintenance and other ecosystem services. A minority of participants projected that HI will remain flat through 2050. While the distinction between harvest time and physiological maturity HI was not made explicitly in collecting participant projections, the comments and flat HI projections represent a recognition that physiological maturity and harvest time HIs may not present the same behavior in a HYS.

Participant Conclusion 3: HI is a crop characteristic that can be engineered to serve market drivers as they emerge and change in a HYS

A point of general agreement was that HI is characteristic that can be selected through breeding and genetic engineering. The economic drivers in current corn production exclusively encourage grain production over biomass production. As yields increase, producers will even put a priority on minimizing biomass other than grain due to agronomic management complications that come from growing quantities of plant material returned to the soil surface.

In considering a HYS, the focus is on absolute productive potential, and thus the participant's agreement on the ability to set HI in future production systems is a critical point for analysis assumptions.

Conclusions

The discussion of harvest index dealt with a range of variables necessary just to put HI in a universally understood context. The key point of consensus among the participants was that market drivers will ultimately lead to genetic selection of species that provide the desired HI. Important participant input recognizes that harvest time HIs are currently increasing with yield growth, but also that HI at physiological maturity is potentially a better metric for determining sustainable removal limits. Furthermore, there is less evidence of substantial HI changes at physiological maturity.

1.2 Alternate HYS Assumption – Environmental Sustainability

The rate of adoption of currently practiced environmentally conscious managements will exceed projections, and innovative new strategies will emerge, both leading to increased stover removal rates.

The baseline extrapolated from USDA 10-year projections (Table 1-1) is based on adoption of no-till and buffer or filter-based conservation management practices implemented with standard continuous corn and corn-soybean rotation strategies. Participants were asked to consider a wider set of innovative management practices that could address environmental sustainability factors and facilitate higher removal rates.

Limiting Factors

Participants identified technical barriers, or "limiting factors," constraining implementation of these innovative management practices and ranked them in order of greatest to least impact on the HYS. Participants' responses are grouped as follows:

Factors that impact environmentally sustainable increased yields (ranked in order of greatest to least impact on the HYS)

1. Wind, rain, tillage, and irrigation-induced erosion constraints
2. Nutrient management and cycling
3. Soil carbon constraints (soil structure)
4. Environmental degradation (nutrient leaching and runoff, decreased diversity, pollen drift, wildlife impacts)
5. Residue management
6. Energy required to produce crop (e.g., nitrogen)
7. Soil water and temperature dynamics
8. Government regulations (carbon trading)
9. Lack of water resources—ground and surface for irrigation
10. Water quality
11. Spatial variability of soils
12. Risk management tools to protect high investment levels
13. Interference (timing) with harvesting operations
14. Inadequate global crop models (GTAP, FAPRI)

1. Wind, rain, tillage, and irrigation-induced erosion constraints

Soil degradation due to erosion losses of productive soil horizons remains a significant concern associated with residue removal. NRCS-administered conservation management planning focuses on erosion from wind and water as compared to soil T values,[83] the allowable erosion loss on an annual basis, in approving grower management plans. Growers seeking to collect stover will have to meet NRCS conservation management planning standards for soil erosion. It was also noted that erosion mitigation is well understood, and it is not a technical constraint, but rather an economic and operational issue.[84]

2. Nutrient management and cycling

Collecting corn stover removes plant nutrients that must be replaced to maintain productivity of the primary grain crop. Several issues emerge with this increased nutrient cycling. Variability in cost, increased leaching and runoff, and increased soil respiration are primary concerns cited as issues associated with increased nutrient application. Growing competition for natural gas between fertilizers and fuels was specifically referenced as a cost concern.[85]

3. Soil carbon constraints (soil structure)

Soil carbon, and subsequently soil structure and health, is widely recognized as a primary limiting factor in residue harvest. As with erosion, it was noted that managing soil carbon levels is not a technical constraint, but rather economic and operational.[86] Agronomic strategies addressing soil carbon concerns are available, but commercial viability is the constraint.[87] The relationship between soil carbon and structure was also noted as critical to limiting compaction effects and, ultimately, primary grain crop production.[88,89]

4. Environmental degradation (nutrient leaching and runoff, decreased diversity, pollen drift, wildlife impacts)

The larger scale environmental impacts of high-yield production scenarios were cited as a primary concern. With increased yield potential, increases in corn acres have historically emerged. Concerns were raised about decreased biological diversity, increased pollen drift, and wildlife impacts resulting from establishment of a commodity market for stover. The aggregate environmental impacts of increased nutrient use and, subsequently, increased leaching and runoff were also cited as primary concerns. Participants noted that strategies emerging in support of residue collection, such as biochar applications, could potentially have unanticipated environmental impacts. It was also recognized that much of the knowledge and technology required to mitigate these concerns already exists.[90]

5. Residue management

The residue management limiting factor as identified in this conversation encompasses the suite of issues at the core of the stover removal discussion. The primary question is "How much residue can I remove sustainably while limiting cost to replace N, P, K and minimizing erosion and SOC loss?"[91] Tillage was identified as a critical part of the residue management discussion. There is currently a perception that tillage is essential to operationally deal will large amounts of stover produced with current yields.[92] Conversely, reduced and no-tillage management practices positively impact erosion, carbon, and nutrient loss limiting factors, thus facilitating greater residue removal.[93]

6. Energy required to produce crop (e.g., nitrogen)

Energy through fuel, electricity, and gas are significant operational costs for agricultural production. Closely connected with those commodities is the availability and cost of fertilizers.[94] Competition for natural gas between fertilizer and fuel production systems could also impact stover collection.[95] It was noted that changes in energy prices will influence food and fuel production systems long before they dramatically influence how energy is used to produce crops.[96] The impact of energy commodity prices on food production could focus production entirely on food commodities, and subsequently overshadow the use of agricultural residues for fuel or energy.

7. Soil water and temperature dynamics

Global climate change and general water availability will clearly play a role in the ability to achieve the HYS. At a finer geographic scale, the surface coverage of residue impacts the local soil moisture and temperature conditions. Variation in these soil conditions can alter critical biological and decomposition processes that are important to soil health and long-term productivity.

8. Government regulations (carbon trading)

Policy decisions could impact stover removal on multiple fronts. Conservation management planning and greenhouse gas emission regulations[97] could be of particular importance. Creating a significant carbon trading market could create value for increasing soil carbon, which could lead to decreased stover collection.[98]

9. Lack of water resources—ground and surface for irrigation

Restrictions on water use could essentially eliminate irrigated acres.[99] While this is mainly a factor in the western United States at the fringe of the "Corn Belt," there is significant production that would suffer.[100] Furthermore, irrigated production systems provide consistent, predictable yields that are appealing to biorefiners exploring siting locations.

10. Water Quality

Delivering quality water is a fundamental ecosystem service provided by agricultural land bases. Increased societal priority and valuation of water quality may force additional costs of production for agricultural systems, subsequently constraining efforts to reach HYS goals.[101]

11. Spatial variability of soils

Variability in soil properties across even single agricultural production units presents significant challenges for consistently sustainable residue removal. The lack of quality slope data[102] limits proper analysis of erosion impacts, and the lack of accurate soil carbon data limits ability to understand carbon impacts.

12. Risk management tools to protect high investment levels

There is significant investment risk associated with participating in this emerging industry, and much of that risk is associated with environmental sustainability constraints. Business plans built upon the best science and engineering available could still have flaws upon implementation. It is critical to allow the implementation to adapt as environmental constraints are better understood.[103]

13. Interference (timing) with harvesting operations

Harvest windows for standard corn production systems are challenging when collecting grain alone. In some years, it will not be feasible to fit additional stover collection operations into these windows. Establishing stover collection equipment that minimizes impact on grain harvest timing could be important.[104]

14. Inadequate global crop models (i.e., Global Trade Analysis Project [GTAP], Food and Agricultural Policy Research Institute [FAPRI])[105]

Understanding global production dynamics and potential will be important to developing corn plants and production systems that achieve the HYS. The potential environmental impacts of these systems are difficult to predict using existing crop models.

Assumption Enablers

The limiting factors were used to brainstorm solutions, or "assumption enablers," that might support environmental sustainability *and* increased corn production. The Assumption Enabler categories and related suggestions are presented in this section in the order of most to least potential impact on ensuring future biomass yield increases are environmentally sustainable:

1. Improve crop and residue management practices

Six themes emerged relative to improved residue and agronomic management practices: tillage, manure and biochar application, nitrogen and fertilizer management, cover crops and living mulches, cropping system and rotational strategies, and economic incentive.

- **Tillage**

  Vertical tillage concepts and techniques were identified as technology with potential to reduce soil disturbance and compaction effects.[106] As HYS production creates more residue in the field, the challenges associated with residue management can potentially lead to tillage designed for residue reduction. These tillage practices can potentially have unintended consequences on soil structure and carbon sequestration.[107] Residue collection in concert with no-till and advanced vertical tillage concepts has the potential to positively impact soil health while helping alleviate challenges created by the presence of large quantities of residue.

- **Manure and biochar application**

  Improvements in manure and biochar application were cited as potentially enabling technologies. Manure application is widely used in modern production systems, but enhanced application techniques such as using a drag line[108,109] and improved injection systems [110] were identified as assumption enablers. These techniques can reduce run and leaching losses and soil compaction, thus leading to significant yield increases and positive environmental impacts. Biochar was identified as a mechanism to help replace the organic matter removed during residue collection with a long-lasting soil carbon amendment.[111,112]

- **Nitrogen and fertilizer management**

  Concepts built on increasing nitrogen delivery efficiency were widely noted by the participants. Several different terms were used to describe these concepts, including: nitrogen inhibitors, [113] nitrogen degradation inhibitors, nutrient stabilizers,[114] nitrogen recovery and recycling,[115] nitrogen fixation,[116] and nitrogen encapsulation.[117] In each case, the advanced concepts work on eliminating nitrogen or other nutrient losses to improve the efficiency between application and plant use.

- **Cover crops and living mulches**

  Cover crops and living mulches have been demonstrated to reduce leaching and erosion, improve soil organic matter, and fix nutrients. Improvements in cover crop[118] and living mulch[119,120] technologies were cited as potential enablers. The potential improvements identified by participants included delayed or late emergence and implementation of low-light cover crops[121] and perennial intercrop species[122] that do not reduce the yield of the primary crop.[123]

- **Cropping System and Rotational Strategies**

  Agronomic strategies that include longer, more robust crop rotations,[124] intercropping techniques,[125] and crop diversity were highlighted as potential enablers.[126] It has been demonstrated that integrated and diverse crop production strategies can positively impact critical ecosystem processes. Continued development of integrated system design and implementation strategies was identified as an enabling technology.

- **Economic Incentive**

  Emerging economic drivers were identified that might incentivize implementation of the innovative technologies and practices described in this section. Specifically, compensation for improved nutrient management[127] and increased cover crop use were cited.[128,129] It was also noted that economic incentives for lower life cycle GHG production systems could speed adoption.[130]

2. Holistic systems approach to crop management

Another enabling concept is adoption of a landscape-scale integrated cropping system approach [131] to production management. A path toward implementation may be development of a series of systems research sites where multiple factors are investigated simultaneously. This approach could start with characterization of soil variability and hydrology. Selection of a diverse mixture of feedstock resources would support high-yield corn production because they can provide buffer areas where nutrient leaks can be captured without environmental degradation.[132]

3. Soil health monitoring

Spatial variability in soils creates significant challenges for tracking the current state of critical soil health metrics. Advances in remote sensing, along with development of systems models that can be optimized using real-time data,[133] have the potential to provide on-demand, accurate soil health information needed to make decisions. These advances will allow monitoring impacts of management approaches so they can be optimized over time based on experience and environment/technology changes.[134] Furthermore, they will facilitate the development of new measures and methods that allow us to monitor true soil and environmental impacts.[135]

4. Advances in crop residue collection technology

Directly coupled to increasing capability for real-time soil health monitoring are advancing crop residue collection technology and developing storage solutions.[136,137] Variable rate residue collection technology was cited as a critical development[138] that would allow flexibility in reacting to soil needs. It was also noted that education and incentives associated with these new systems will be necessary to encourage adoption.[139]

5. Strategic use and redevelopment of wetland for water runoff and tile management

Leveraging ecosystem services provided by other landscape features can help mitigate environmental impacts from high-yield production. For example, about 10% of a watershed can be devoted to a wetland capture surface runoff and tile drainage. Wetlands would also aid in flood control, reduce stream volumes, aid in erosion control, and improve water quality.[140] Compensating landowners for this service may encourage this solution.[141]

6. Better government policy

The participants noted that, at least temporarily, effective incentive structures need to be developed to improve sustainability as we move toward utilizing residues.[142] To facilitate the implementation of these incentives, reliable models need to be developed and employed.[143] Furthermore, broad and consistent sustainability standards need to be established across agencies and levels of government.[144] One participant noted that when metrics are developed and incentives attached, farmers manage to the metric.[145]

7. Economic modeling to optimize environmental actions

Participants saw significant potential in the advancement of economic models and risk analysis tools to support the optimization of management decisions relative to environmental actions and consequences. The relationship between residue removal, increased nutrient application, and water quality was cited as a challenging problem with current decision tools.[146] Extending the complexity of that problem is the potential for societal emphasis on valuation of ecosystem services, with water quality identified as likely to appear first.[147] The participants cited valuation of ecosystem services as a potential enabler,[148] but they also recognized that risk analysis tools are needed[149] to support the investments that would be made.

8. Distributed processing technologies

The emergence of distributed pre-processing systems for cellulosic biomass materials was identified as an enabling technology.[150] It was noted that these systems may bring back a previously common storage system: Harvestore silage silos.[151]

9. Effective government carbon trading

A specific ecosystem service, carbon credit trading, was discussed as an enabling assumption. It was noted that one challenge is development of valid baseline carbon levels for soils[152] followed by effective and accurate monitoring of the impacts to soil carbon under implemented management scenarios.

10. Fleet management for new farm scale

Consolidation of farm operations leading to increased acreages under the control of fewer managers was cited as enabling the implementation of more technology to improve logistics, remote data access, and work order processing.[153] This would subsequently have the potential to support several of the other enabling assumptions identified in the discussion.

Projecting Adoption of Environmental Sustainability Practices Sufficient to Support HYS

Figure 1-6 highlights the top four enabling assumptions for environmental sustainability criteria as identified by the participants. The participants were asked to select the timeframe for sufficient adoption of the solutions to enable the HYS. All twelve participants estimated that "Improve residue/agronomic management practices" and "Holistic systems approach to crop management" enabling solutions could be sufficiently adopted by 2022 to support the HYS. "Soil health monitoring" technology was estimated to be sufficiently adopted by 2022 by 10 of 12 participants, and "Advances in residue collection technology" by 11 of 12 participants.

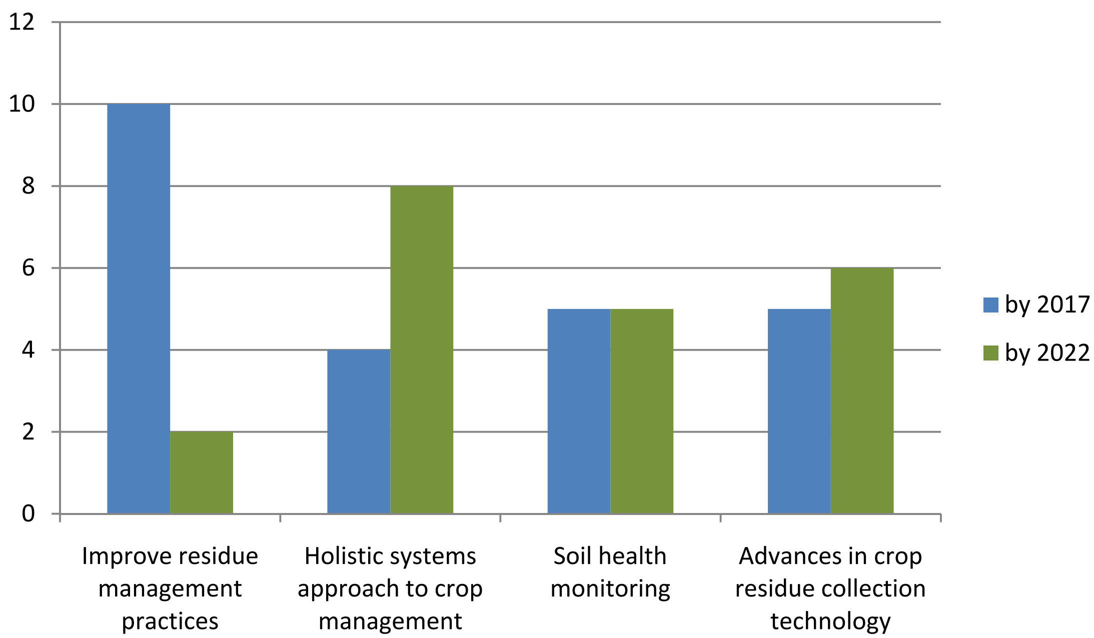

Figure 1-6. Number of participants who estimated the timeframe for sufficient adoption of the most promising and likely-to-occur solutions to support the HYS.

1.3 Alternate HYS Assumption – Economic Viability

Economic conditions are met that incentivize producers to manage and sell residues.

Economic issues were purposefully redirected from the yield potential discussion because, for this exercise, it is assumed that a market demand will exist where there is none today. Current economic models operating without this future demand cannot reliably incorporate pricing influences on crop production as biomass markets enter the commodity picture, and modeled economic reactions can obscure assessment results. Economic-related concerns will, in truth, significantly impact resource availability, science and technology advancements, and more generally constrain or enable achievement of the HYS. Participants discussed a broad range of economics-related issues and suggested actions that can support establishment of biomass as a commodity.

Limiting Factors

Factors that impact economic viability of the HYS

1. Corn grain yields negatively impacted by residue collection
2. Corn grain harvest logistics negatively impacted by residue collection
3. Value of residue too low to cover
4. Lack of opportunity to participate in residue value chain
5. Markets for residues currently unavailable
6. Financial risk.

Participants were asked to identify economics-related barriers, or "limiting factors," that prevent producers from becoming actively engaged in corn residue management and selling, and thus constrain establishment of a commodity-scale market for agricultural crop residues. Establishing biomass as a commodity is an economically complex undertaking and involves interactions throughout the entire supply chain, from providing incentive for growers to produce feedstocks, through conversion and distribution of the final product. The current economics behind managing and selling corn residues do not provide producers a reasonable incentive to participate in the production of bioenergy feedstocks. Their lack of participation results in significant risk to biorefiners and, if not addressed, will ultimately undermine the establishment of a bioenergy industry.

Participants presented the following limiting factors and related concerns:

1. Corn grain yields negatively impacted by residue collection

One of the factors of concern was that over time, future corn grain yields may be negatively impacted by residue collection and other variables such as moisture, weather, and nutrients,[154] which will impact management and production costs. Management practices can also be an economic limiting factor.[155] Management practices over the past half century have been developed for grain removal, and the management paradigm shift for grain *and* stover removal is a high financial risk because producers may not understand the long-term impact to soil and yield effects.[156,157] Stover removal can have positive or negative effects, depending on seasonal weather patterns and management decisions.[158,159] An example provided was areas northwest of Des Moines, Iowa, where growers have been removing stover for years and are now starting to see negative impacts on grain yield.[160] Other studies mentioned indicate that, depending on weather conditions, crop yields, and local field conditions, the option to remove residue can be a beneficial management option,[159] enabling warmer soil temperatures, better early season vigor, more uniform germination, and reduce tillage in corn/corn rotation plantings.[161]

2. Corn grain harvest logistics negatively impacted by residue collection

The residue harvest and collection logistics can also be an economic limiting factor because the harvest window for this operation comes at a busy time of year[162,163] and is highly sensitive to weather variables.[164]

3. Value of residue too low to cover

The market value of residue is an important consideration to both the producer and end user. Its value must be great enough to cover removal costs, nutrient replacement costs, complications due to planting and harvest windows, and capital expenses associated with residue removal and storage. These costs impact the business model regardless of end use (i.e., biochemical, thermochemical, or chemical reactor).[165] If the economics for the end user business model do not make sense in the long run, this business is not sustainable.[166]

4. Lack of opportunity to participate in residue value chain

An investment in the genetics and production management of higher quality biomass could increase residue market value,[167] but there is considerable uncertainty about the specific quality improvements needed and their value relative to grain.[168] Some anatomical parts and portions of the stover are more valuable than others and differ in terms of processing efficacy as well as in moisture content and degradability. Plant parts are important; [169] for example, at harvest, the upper portion of the plant including cobs is more valuable in some applications because of lower water content and less soil contamination,[170] but it is not clear who captures this upgraded value, the producer or end user.

The concern is that if producers are not rewarded for their adoption of new hybrids and management practices that upgrade the residue value,[171,172] they will not participate. At the individual production-scale level, there is a need to know the in-field nutrient status, including residue nutrient composition, before producers move into a new management scheme. Most producers are not familiar with extra nutrient removal associated with residues.[173] New technology to harvest variable amounts of biomass per unit area and spatially document actual removal needs to be developed.[174] The development and adoption of this technology, including affordable, on-farm preprocessing technology, will facilitate producer participation.[172] New methods developed to densify and stabilize feedstock[175] for longer term storage is another opportunity to add value by preventing biomass quality degradation and other storage losses.[176]

5. Markets for residues currently unavailable

Another limitation to developing a biomass feedstock market is the current lack of demand for the biomass feedstock because of the lack of nearby biochemical, thermochemical, or chemical refinery facilities. Transporting feedstock long distances to end users adds to its cost.[177,178,179]

6. Financial risk

All of these limiting factors and concerns require risk management[180] and contingency planning[181] solutions. There is a big need for crop and liability insurance to cover on-farm storage fire risk and consequences for not delivering on biomass feedstock contract.[182,183] These risks are compounded by the impact of weather on the harvest window and resulting degradation of feedstock quality.[184,185] Producers risk running out of time to handle the grain *and* stover harvest within the limited harvest window of a typical Midwestern harvest.[186] Adding to the risk is a current lack of qualified labor during the harvest period.[187]

Assumption Enablers

The limiting factors were used to brainstorm solutions, or "assumption enablers," that might support economic viability of a commodity-scale market for agricultural crop residues.

Several assumption enablers were identified that may help address economics-related limiting factors, including high removal costs, high nutrient replace costs, complications due to planting and harvest windows, and capital expenses associated with residue removal and storage.[188,189,190] Assumption enablers were not organized and ranked by the participants as part of the discussion, but their responses are easily categorized under three themes: (1) market viability, (2) return on investment; and (3) risk aversion tools, strategies, and policies.

1. Market viability

Corn stover and other agricultural crop residues currently have a value too low to cover basic business element costs, such as removal, nutrient replacement, complications caused by sensitive planting and harvest windows, capital expenses associated with residue removal and storage, and the impact these factors have on the biorefinery/end user business model.[191,192,193,194] Participants suggested that market viability can be supported by prioritizing crop development for a both grain and residue yield and striving to maintain a constant harvest index.[195,196] Development of innovative landscape-scale management strategies that reduce inputs and increase yields may also support economic viability.[197]

2. Return on investment

Lack of return on investment is currently a barrier. Unless producers receive high enough returns through the increase in demand for corn and residues, they will not purchase the new higher yield products, including those improved by biotechnology R&D.[198] However, if a market materializes, producing both grain and biomass as cash crops would increase farm revenues and will support economic viability.[199] Economic incentives for lower life cycle GHG corn could speed adoption of new technologies that result in higher biomass and grain yields (or spur off-field uses of stover to lower system carbon balances).[200,201] There are biotech solutions for increasing biomass productivity, but they currently are being "shelved" because the focus on yield improvement has been on increasing grain yield not stover.[202]

Participants also anticipated reduction in costs of equipment as harvest and collection efficiencies are improved. Reduction in costs will come with improved efficiency of equipment, which will provide new equipment options from which farmers may choose for their specific applications.[203,204] These equipment options may incorporate on-farm, affordable preprocessing technology for densification and stabilization of feedstock for longer term storage. This will help prevent quality degradation that occurs during storage.[205,206]

The Biomass Crop Assistance Program (BCAP) will also play an important role in providing investment incentive and helping get residue production started. This will, in turn, stimulate the development and distribution of more efficient equipment that currently is not available to producers because of capital expense.[207,208, 209]

3. Risk Aversion Tools, Strategies, and Policies

To give growers, producers, and bankers' confidence to invest, participants identified the need for reliable cost models[210,211] that (1) are validated with realistic field testing,[212] (2) incorporate real-world data[213] and long-term contracting options,[214] and (3) take into account the variation in feedstock supply quality and quantity.[215] To reduce financial risk, long-term biomass feedstock contracts are needed,[216] which will be typical of other biomass buyers, such as power generation.[217] R&D is needed on investment incentive programs and should include both public and private investment and take into consideration trends in land tenure. Acreage in corn production is now 60–80% absentee landowners, which changes the business dynamic between landowners, producers, and lending institutions.[218] Risk must be distributed. Producers cannot be expected to bear the risk of a program that is discontinued after they have invested.[219] Education will be crucial for the success of those programs.[220,221]

1.4 Alternate HYS Assumption – Land Use

Land-use change is based on net returns resulting from landscape-scale management of multiple products, including ecosystem services, to ensure sustainability (i.e., land is used according to its best value).

Land-use change is currently driven by near-term returns produced by the grain crop alone with little control over positive or negative impacts. As markets develop for commodity-scale corn stover and other agricultural crop residues, it is foreseeable that nonproductive land will move into production. There are concerns that changes in world land use will negatively impact climate conditions and vice versa. There are also concerns that residue removal incentives encourage unsustainable land management practices and negatively impact future production and the environment.

Participants were asked for their opinions about land-use issues related to increased demand for biomass resources. Discussion prompts included integration of energy crops into cropping systems, germplasm improvements that may expand the range and productivity of bioenergy crops, and how better management practices might allow for expansion of biomass production into Land Capability Class (LCC) III, IV, V, and VI lands.

Limiting Factors and Assumption Enablers

The discussion was brief, but participants emphasized the following observations and concerns:

Factors limiting the availability of land for crop expansion include competition for agriculture crops versus livestock production, as well as loss of agricultural lands to urbanization as the human population increases.[222] To counter these, there is the potential of using public lands and marginal lands that are currently in the Conservation Reserve Program (CRP) for producing biomass feedstock. The use of public lands for biomass production could increase feedstock availability, but this is currently restricted by policy. Changes in government policy will be required to enable the use of public lands for commercial biomass production.[223] There are constraints inherent in the use of CRP lands for biomass as well, as a large percentage of reserved lands are in the arid western states, where dry growth conditions limit productivity.[224]

There is good potential, however, to realize yield increases if a portion of marginally productive lands (including CRP) are brought into productivity. Improved genetics and management practices are improving yield in these LCCs, and while high-productivity and irrigated lands will realize greater average yields,[225,226] marginal lands have a greater potential for increasing rates of gain in corn yield. For example, over the last 20 years, production of dryland corn has dramatically increased[227] and is now grown economically in areas as far west as Colorado. To continue this expansion, more field trials and data analysis are needed to identify which germplasm combination best responds to increasingly challenging environments. With an array of diverse germplasm to select from, in combination with powerful biotechnology methods, plant breeders have an opportunity to select higher yielding genotypes for stover and grain production in less favorable environments.[228]

The anticipated trend is expansion of corn acres as driven by the demand of both grain and stover.[229] To date, corn acres have grown rapidly, and this growth is expected to continue as long as net returns from corn production exceed those from other uses of the land.

1.5 Alternate HYS Assumption – Other Technology/Policy Advances

Other technologies, research initiatives, and policies that will impact future corn residue availability are identified.

Concluding discussions allowed participants to present additional thoughts about other technologies, research initiatives, and policies that will impact future corn residue availability. Participants were asked for any additional suggestions that had not been presented in earlier discussions sessions, such as needed changes in crop residue collection technologies to improve stover availability, technology advances that might enable abundant supply to all biomass markets, and federal research initiatives that might adequately outline and fund near- and long-term feedstock production and supply R&D and policy needs.

Limiting Factors and Assumption Enablers

The discussion was brief, but participants emphasized the following observations and concerns:

As the most efficient energy capture crop, corn is a natural "bioprocessing plant".[230] More research and development has been invested into corn than any other crop and has enabled it to dominate the agricultural landscape as the most productive crop in the United States.[231] Corn is the foundation of our bioeconomy going forward. It is an anchor because of the plethora of products derived from its grain.[232] Other countries are becoming more self-sufficient by growing their own grain because food security is even more important now than energy security.[233] Corn is preferred because it is more profitable than any other crop.[234] The forecast for seed sales indicate an increase for next year, if fertilizer stays affordable, but there is growing world competition for corn and increased corn acres will be planted. Because of this global expansion in corn acreage, the United States cannot depend on the export market to drive the demand for increasing corn yields.[235] As the HYS is realized, the 15 billion gallon cap on corn ethanol may need to be reconsidered and raised.[236] The shift in demand for the use of corn for ethanol versus food depends on the rate of gain in corn productivity and the cost of energy.[237] The shift also depends on the impact that land use change has on livestock production, which is a major market for corn. If livestock supply goes out of country, corn demand will drop, freeing up more gain for ethanol production.[238] Alternatively, stover may become a more common cattle feed ingredient, freeing up grain for other uses.

Because of the current and other potential high-value products that can be derived from corn grain, it is important to also consider maintaining the stability of these high-value product markets as demand pulls its use toward competing bioenergy products.[239] Depending on the price of oil, other important product lines, such as esters and hydrocarbons, may be profitably produced from corn.[240] For example, the amino acid composition of dried distillers grains (DDG) could be improved for use to supplement the nutritional value of soybean meal. This would complement the expansion of soybean production by Brazil.[241]

Workshop Participant Bios

Steven C. Barr

Since 2006, Steven C. Barr has been a consulting engineer for DuPont Engineering Research and Technology. His work on life cycle assessments includes leading LCA of the Butamax™ biobutanol process for directing R&D and external communications, and performing literature searches to determine a switchgrass farming LCA model. He has also developed techno-economic assessments for business decisions; this has entailed estimating costs of various production options for biofuels, including thermochemical and biological and developing an economic model for evaluating algae biofuels production options. Prior to this, Steven was employed for six years at Honeywell International as a senior process engineer in Specialty Materials. His experience includes work in vaccine technology and engineering, as well as process engineering.

Michael D. Edgerton

Michael D. Edgerton received his Ph.D. in Biology from the University of North Carolina at Chapel Hill in 1992. Since May of 1998, he has worked in various capacities for Monsanto, including technology lead for the corn technology and quality traits project, function lead for the yield stability project, project lead for the corn new traits project, and functional lead for the gene selection project. He also worked as a project leader in the Bacterial Genomics Program for Glaxo Wellcome in Geneva, Switzerland, where he assembled and led an international research project that successfully sequenced two bacterial genomes. For this program, Dr. Edgerton also identified and patented novel essential broad-spectrum antibiotic targets. He is author or co-author of several publications and holds 15 patents in such topics as transgenic plants, recombinant polypeptides in plants, and selective gene expression in plants.

Douglas Haefele

Douglas Haefele holds a Ph.D. in molecular microbial ecology from the University of California at Berkeley. Since 1986, he has worked as senior research scientist at Pioneer Hi-Bred, a DuPont business. His responsibilities include identifying opportunities to differentiate the value of corn to grain processing end-users and the development of analytical and bioassay techniques for quantization of compositional and functional properties of corn grain. Dr. Haefele is a member of the American Association for the Advancement of Science, as well as Sigma Xi, the Scientific Research Society.

Larry Hasheider

Larry Hasheider is a livestock and grain farmer who serves as chairman of the National Corn Growers Association (NCGA) Research and Business Development Committee and Chairman of the Illinois Corn Marketing Board Industrial Committee. In 2007, Mr. Hasheider was honored as the Irrigated State Corn Yield Winner in a national NCGA corn yield contest. He is also the board director for Farm Credit of Illinois. In the past, he has served as president of the Kaskaskia Watershed Association and president of Original Kaskaskia Area Wilderness, Inc., which required his collaboration with the Illinois Department of Natural Resources.

Douglas Karlen

Douglas Karlen received his Ph.D. in Agronomy from Kansas State University in 1978. He is currently a supervisory soil scientist and research leader for the National Laboratory for Agriculture and the Environment (NLAE). He has extensive experience as a soil scientist for such institutions as the Coastal Plains Soil & Water Conservation Center in South Carolina and the National Soil Tilth Laboratory in Iowa. Dr. Karlen has authored or co-authored 281 refereed journal or proceedings papers and 152 technical abstracts. He has received numerous honors and award, including recognition in Who's Who in Science and Engineering, 16 USDA-ARS certificates of merit, and fellowship in the American Society of Agronomy. Dr. Karlen is a member of many organizations, including the Crop Science Society of

America (CSSA), Soil Science Society of America (SSSA), Soil and Water Conservation Society (SWSC), and the International Soil & Tillage Research Organization (ISTRO).

Kendall Lamkey

Kendall Lamkey received his Ph.D. in plant breeding and cytogenetics from Iowa State University in 1985. He is presently department chair for Iowa State University's Department of Agronomy, having previously served as interim chair. He has co-authored many publications and symposia papers, including "Plant Breeding: Past, Present, and Future" (2006) and "Genetic Variation and Breeding Potential of Phytate and Inorganic Phosphorus in a Maize Population" (2008). Dr. Lamkey is a member of the American Society of Agronomy, Crop Science of America, and the American Association for the Advancement of Science.

David Loos

David Loos is the Technology and Business Development director for the Illinois Corn Marketing Board/Illinois Corn Grower's Association. He is responsible for collecting and analyzing technical, economic, regulatory, political and social information relevant to market development projects. He works with companies, outside organizations, and/or individuals whose projects involve new and innovative technology. In addition, Mr. Loos manages the Illinois Corn Marketing Board's (ICMB) research program as well as solicits and evaluates research proposals and works with universities and industry on patent and royalty issues representing the ICMB. He supports the Illinois Corn Growers Association (ICGA) by evaluating and helping with commercial adoption of technologies and identifying legislative initiatives that provide funding and/or set research direction. Finally, Mr. Loos serves as the technology expert to both the ICGA and ICMB.

Todd Mathisen

Todd Mathisen has 32 years' experience as a corn and soybean farmer on a 2700-acre farm that has been in his family since the 1870s. For the first 25 years of this time, he also fed cattle and hogs. Mr. Mathisen not only harvests corn kernels to sell for ethanol production, he also harvests the cobs for cellulosic ethanol using specialized machinery and a streamlined process that will maintain productivity. He is on the Cob Collection Development Board and is a member of the Corn and Soybean Association.

Todd Peterson

Todd Peterson holds a Ph.D. in Agronomy from the University of Nebraska at Lincoln and is a visionary leader in agricultural sciences with expertise in marketing and bringing innovative precision farming solutions to growers and their advisers. He is an effective manager with experience directing large multi-disciplinary R&D projects and leading collaborations across geographies, affiliations, and disciplines. Dr. Peterson is an effective written and oral communicator. He is deeply committed to helping crop producers adopt technology that adds value to their operations while protecting the environment. Among his strengths are building and managing teams, managing strategic alliances, consensus building, and budget and finance.

Raymond Riley

Raymond Riley holds a Ph.D. in Plant Breeding and Genetics from the University of Nebraska. He is currently employed at Syngenta Seeds, Inc. as head of global corn and soybean research and product development. In this capacity, Dr. Riley is responsible for R&D efforts in support of Syngenta's global business strategy. He has held numerous research director positions in which he furthered corn product development in many parts of the world, including China, Africa, and South America. Dr. Riley is a member of the American Society of Agronomy and Crop Science Society of America as well as the Iowa Council for International Understanding.

Michael C. Roth

Michael C. Roth is a process engineer for POET. He holds two M.S. degrees—one in Business Administration from the University of Sioux Falls, and one in Chemical Engineering from the South Dakota School of Mines and Technology. Since 2001, Mr. Roth has held many leadership positions at POET, including director of Special Projects, director of International Business Development, and director of Site Development. He is currently director of the Biomass Program. In 2007, Mr. Roth presented "The Future is Now: Cellulose Ethanol" at the Atlantic BIOEnergy Conference and the Biofuels Markets Asia in Singapore.

Lee Stromberg

Lee Stromberg holds a Ph.D. in Plant Breeding and Genetics from the University of Illinois-Urbana and is currently manager of Seed Activities for BASF, a company that works to optimize crops for more efficient agriculture, renewable raw materials, and healthier nutrition. With 12 years' experience as a corn breeder and 7 years' experience as a research manager, Dr. Stromberg's research focuses on improving the nutritional qualities of maize as feed for poultry, swine, and dairy cattle, including measuring the starch, oil, protein, amino acid levels, and agronomic traits in corn hybrids in order to optimize the balance for different animal species.

Workshop Notes and References

1. USDA National Agricultural Statistics Service (NASS) (2009) National Statistics for Corn. http://www.nass.usda.gov/Data_and_Statistics/
2. Much yield variability has been reduced by modern agronomics is the last 10 years, i.e., healthy roots and machinery. Yield variability has also been somewhat reduced through breeding and biotech (insect resistance).
3. Biggest barrier to a high-yield scenario is yield variability management.
4. In the U.S. warmer temperatures are likely to increase pest, weed and disease pressure. These will be discussed under the individual topics. In addition, intermittent drought and loss due to severe weather may increase and should be considered in the economic and supply models. This is particularly true on a local basis where a county level area may be damaged by wind or hail.
5. Suggest looking at each separately as these are managed differently. Insect pests managed by insect selective toxins. Expect this to be an ongoing process as new pests begin to inhabit the niche and/or resistance evolves. Fungal disease - managed by breeding, good use of diversity, markers.
6. Increased irrigation demand will impact water resources.
7. Marra, M.C., Piggott, N.E., & Goodwin, B.K. (2010). The anticipated value of SmartStax™ for U.S. corn growers. AgBioForum, 13(1), 1-12.
8. Biotech has “solved” the problem of two of the biggest corn pests – CRW and ECB. Assuming these genes remain effective, additional gains by going after other insects may not produce significant results.
9. We are starting to see the first products developed from molecular breeding. Corn yields in 2009 showed dramatic hybrid differences at very high yield levels with hybrids released just a few years ago showing a yield plateau at 240-250 bua, with the newest genotypes producing 300+.
10. Weather (rainfall, heat) is the #1 factor to annual grain yield – everything else comes after weather. Weather can easily have a 2x factor on yield - from 100 bu/a to 200 bu/a on the same field is possible with the same hybrid in two consecutive years.
11. Temperature Trends Over Time - as daytime temperatures increase or decrease and night time temperatures do the same - there will be tradeoffs on yield that can only be determined by modeling. For example, daytime temperatures in Iowa are decreasing, but nighttime temperatures are increasing. Lower daytime temperatures increase yield, but higher nighttime temperatures will decrease yields.
12. Economic limitations (cost increases due to natural gas prices, GHG or water quality legislation) could slow rate of yield growth. One the positive side, selection is being done at more or less constant N. There is variation in NUE across hybrids/inbreeds but this is not explicitly selected for using variable rates of N. There is an implicit selection for NUE (and P/K) due to selection for yield. There is some evidence that this is selecting for corn with lower grain protein levels. In projecting nutrient requirements I’d suggest letting NUE increase to ~75% and slowly allowing grain protein to drop to 6-7%.
13. Farmers may not always go after “maximum” yield. They may go after maximum profitability. As N prices increased, farmers tended to apply less. So it may produce more farm income to reduce N and reduce yield.
14. Assume we are dealing with total nutrient use efficiency – not simply fertilizer use efficiency; i.e., nutrient cycling within the soil system as well as fertilizer input.
15. Current soil maps are only very rough estimates of the actual soil that is present. This is also related to very poor slope estimates. Some states will soon have lidar data available which will help on both of these points.
16. The current soil type characterization system may not help us very much in predicting potential corn yield; I would like to see research developing an index essentially describing a spatial estimate of the size of the sponge under each plant.

17. Projections must account for spatial variability at least at the section level (640 ac) as there are parts of each field where NO residue can or should be removed; other parts where as much as 80% might be safely removed without impacting sustainability.
18. Disease and Pathogens.
19. With grain and biomass as cash crops, we can increase revenue to the farm.
20. Unless the producer receives a high enough return through the increased demand for corn, they will not invest in purchasing the new biotech technologies.
21. Price and producers' returns will ultimately influence biotech research investment.
22. Energy costs do impact crop management priorities. On farm energy cost impacts ROI for fertilizer, tillage, transportation, and grain drying.
23. All of the prices mentioned for grain and biomass need to fit within the business model of the end user (ethanol or power producer), finding an appropriate pricing strategy for the biomass is of utmost importance to the viability of biomass collection.
24. Current increases in yield are highly correlated to increasing plant densities. What will keep this going?
25. Interaction with weather (climate change) influences response to higher populations, e.g., 2009 in central Iowa was very cloudy and there was no yield difference between 32K and 44K plant population.
26. Regarding (46) – the cost to plant 32k vs. 44k is much less and with no yield difference my farm makes more money.
27. Most corn yield contest winners are corn following soybean.
28. And ways to deliver benefits of rotation though alternate means.
29. Corn on corn rotation reduces yields 5-15% vs. corn-soy rotation.
30. Availability? From a supply perspective or crop|soil interaction?
31. Nitrogen fixation?
32. Government policy is high impact on corn.
33. Mandatory demand for cellulosic feedstocks could drive increased stover yields and slow increase of corn grain yields.
34. Limited ethanol demand due to government policy and blending limits.
35. EPA regulations re: Atrazine and others, looking at EPA regulations for different chemicals.
36. There are biotech solutions that could increase biomass, but for the most part they are being "shelved" because the focus is on increasing grain yield, not stover.
37. Tech provider's next barrier is lack of ability to capture those returns.
38. Landscapes vary and are controlled by biological processes; need to address yield (productivity), carbon sequestration, water quality, biodiversity, wildlife, community development, together and overall yields will advance. Need to think about alternative solutions - other than rotating, are there other ways to manage soils, etc. Pressure to produce more volume today limits our future volume - optimize landscape – monoculture and How would this be implemented? Would it be mandated? We could create economic incentives.
39. Especially societal acceptance, trait approvals, global grain flow acceptance, etc.
40. Need to analyze stover collection methods and ratio to corn. Could other include water use efficiency. Competition between rural and urban for water aquifers.
41. Are we trying to increase the acres in area of immediate plant or just enlarge corn belt? Distance is an issue. For this workshop let's focus on overall corn volume - enlarge the production perimeters. You end up with a set of corn markets - let's suppose dry land corn to 100–150 tons may not be enough for stover removal but

will add to grain harvest, so it becomes a supply question. What if there is enough hybrid adoption in Mexico that they increase production dramatically?

42. Adapted from Evans LT and RA Fischer. 1999. Yield potential: Its definition, measurement, and significance. Crop Science 39:1544–1551.

43. We are starting to see the first products developed from molecular breeding. Corn yields in 2009 showed dramatic hybrid differences at very high yield levels with hybrids released just a few years ago showing a yield plateau at 240–250 bua, with the newest genotypes producing 300+.

44. Selection of superior varieties, biotechnology, molecular breeding {facilitator}; regulation of gene expression.

45. I would separate biotechnology from this category. Development/selection of superior varieties has gone on for years, and will continue. Molecular breeding will hopefully accelerate this rate of gain. I think of "biotechnology" as adding a dimension not available through conventional breeding - for example, making a corn plant produce Bt to control ECB.

46. Eathington S.R., Crosbie T.M., Edwards M.D., Reiter R.S., Bull J.K. 2007. Molecular markers in a commercial breeding program. Crop Science 47(S3): S154-S163.

47. Cooper M, Messina C, HausmannN, Winkler C, PodlichD (2009) Breeding Maize for Drought Tolerance in the US Corn□Belt. 45th Illinois Corn Breeders School http://imbgl.cropsci.illinois.edu/school/presentations/2009/Cooper.pdf

48. DuvickDN, Smith JSC, Cooper M (2004) Long□term Selection in a Commercial Hybrid Maize Breeding Program. In Plant Breeding Reviews, Volume 24, Part 2: Long□term Selection: Crops, Animals, and Bacteria. pg 109□151. JanickJ (ed)

49. What are the upper limits related to spatial variations.

50. It's hard to imagine a top-end plateau for the yield by plant density response curve... each time we predicted such a plateau we have been proven wrong. Corn breeders continue to give us plants that tolerate closer neighbors.

51. Sarlangue T, FH Andrade, PA Calvino, LC Purcell (2007) Why do maize hybrids respond differently to variations in plant density? Agonomy Journal 99:984–991; Boomsma CR, JB Santini, M Tollenaar, TJ Vyn (2009) Maize morphophysiological responses to intense crowding and low nitrogen availability: an analysis and review. Agronomy Journal 101:1426–1452.

52. Biotech has "solved" the problem of two of the biggest corn pests - CRW and ECB. Assuming these genes remain effective, additional gains by going after other insects may not produce significant results.

53. Insect pests managed by insect selective toxins. Expect this to be an ongoing process as new pests begin to inhabit the niche and/or resistance evolves. Fungal disease - managed by breeding, good use of diversity, markers.

54. The results of high yield contests indicate that significant advances in management can be made to increase corn yields. The major difference between "average" yields and yield contest yields is management.

55. However, NCGA yield maxes have not really increased on irrigated plots since the mid 1980's - see IA State Article "Are we capable of producing 300 bu/a corn yields."

56. Iowa State University Agronomy Extension (ISU) (2007) Are we capable of producing 300bu/ac corn yields? Crop production. http://www.agronext.iastate.edu/corn/production/management/harvest/producing.html.

57. Real-time internet wireless access in field, real-time sensing and image processing. What types of data should/can we be monitoring? Weather/climate, lots of things, and feed it by remote sensing acquisitions to crop growth models and fungicide (economic) models.

58. We need to be working in scales you can model. Landscape databases need to link to genomic databases. One challenge is resistance to put real data in. If tractor has sensor of inputs and collects that, this could be fed to databases.

59. We don't know what is going on at the field level on yields over time.

60. Where can we locate these information collecting systems? I think at the co-op level. We have the ability to monitor data on yield, which seed in which part of field, on every variety of co-op. This is a practical example of information handling that would increase overall the productivity in the county. So how do we apply that same capability to other inputs and practices? Maybe someone in the middle, between seed sales and government.

61. We could collect GIS info from combines.

62. However, NCGA yield maxes have not really increased on irrigated plots since the mid 1980's – see IA State Article, "Are we capable of producing 300 bu/a corn yields."

63. It's hard to imagine a top-end plateau for the yield by plant density response curve... each time we predicted such a plateau we have been proven wrong. Corn breeders continue to give us plants that tolerate closer neighbors.

64. Sarlangue T, FH Andrade, PA Calvino, LC Purcell (2007) Why do maize hybrids respond differently to variations in plant density? Agonomy Journal 99:984–991; Boomsma CR, JB Santini, M Tollenaar, TJ Vyn (2009) Maize morphophysiological responses to intense crowding and low nitrogen availability: an analysis and review. Agronomy Journal 101:1426–1452.

65. Development/selection of superior varieties has gone on for years, and will continue. Molecular breeding will hopefully accelerate this rate of gain. I think of "biotechnology" as adding a dimension not available through conventional breeding - for example, making a corn plant produce Bt to control ECB.

66. Tolerance to drought, pest, climate change, and other stress factors.

67. Campos H, M Cooper, GO Edmeades, C Loffler, JR Schussler, M Ibanez (2006) Changes in drought tolerance in maize associated with fifty years of breeding for yield in the U.S. corn belt. Maydica 51: 369-381.

68. Progress in gene switching technology is likely to lead to genotypes that turn on adaptive mechanisms only as needed.

69. Breeding technologies (doubled haploids, high quality off season nurseries, wide area testing...).

70. Biotech has "solved" the problem of two of the biggest corn pests - CRW and ECB. Assuming these genes remain effective, additional gains by going after other insects may not produce significant results.

71. Insect pests managed by insect selective toxins. Expect this to be an ongoing process as new pests begin to inhabit the niche and/or resistance evolves. Fungal disease - managed by breeding, good use of diversity, markers.

72. To make the plant more efficient in producing grain, my hunch is that something has to give - and that will likely be green plant / biomass.

73. Literature provided by M. Edgerton: Barten, T (2009) Harvest index vs. yield.

74. Genetic breeding for higher stover levels with bioenergy market.

75. With emergence of bioenergy market will increase harvest index.

76. It's certainly possible to increase stover levels through breeding - but it's at odds to increasing grain, which is what the majority of breeding programs are focused on today.

77. Harvest index in 1940's was ~0.35, today about 0.53, 0.60 is probably max with current technology.

78. Current price incentives drive research to direct plant energy to producing grain rather than stover.

79. Are we designing for grain production or stover and what are the tradeoffs.

80. It is possible that non-grain biomass per unit land area will need to increase as plant population increases.

81. Sawyer J and A Mallarino (2007) Nutrient removal when harvesting corn stover. Integrated Crop Management August 6, 2007. ref http://www.ipm.iastate.edu/ipm/icm/2007/8-6/nutrients.html

82. Lorenz AJ, TJ Gustafson, JG Coors, N de Leon (2010) Breeding maize for a bioeconomy: a literature survey examining harvest index and stover yield and their relationship to grain yield. Crop Science 50:1–12.
83. Soil t values.
84. Not a technical constraint; it is simply uneconomical.
85. Natural gas competition – fertilizer vs. fuel.
86. Not a technical constraint we know how to increase soil carbon; it is simply uneconomical in the current system.
87. Knowledge exists; economic limits.
88. Soil tilth as a separate item from soil carbon.
89. Soil compaction.
90. Is this actually a technical constraint? Knowledge to address these questions already exists.
91. How much residue can I remove sustainably while limiting cost to replace N, P, K and minimizing erosion and SOC loss?
92. Perception that tillage is essential.
93. Tillage practices will also play a major role the residue management.
94. Available supply of nutrients (purchase).
95. Natural gas competition – fertilizer vs. fuel.
96. Changes in energy prices will influence food/fuel production systems (food sheds) long before they dramatically influence how we use energy to grow a crop.
97. Greenhouse gas emissions.
98. Carbon cap and trade could create value for increasing soil carbon, which could lead to decreased stover collection.
99. Water use restrictions.
100. This is mainly a factor in the western US - at the fringe of the “Corn Belt.”
101. Society may dictate this a higher priority… force agriculture to address the external costs of production.
102. Lack of quality slope data.
103. Business plan with best science knowledge available - shouldn’t be punished if it changes, you just need to adapt; shouldn’t get ostracized because you thought it was the right thing and it wasn’t; acceptable risk; government regulations to incentivize - probably need better models so they can do this; decision tools; models.
104. What biomass collection equipment is available and how does is the equipment used to not interfere with harvesting grain.
105. Inadequate global crop models. (GTAP, FAPRI).
106. Vertical tillage concept.
107. Tillage focused on residue reduction may have unintended consequences on s oil structure and carbon sequestration; vertical tillage for minimal soil disturbance.
108. Using a drag line to apply manure.
109. Vertical tillage – new technology and some companies are producing equipment to do it.
110. There is also an injection system for manure that has demonstrated significantly increased yield; it’s not a tanker, so there is no compaction. It encapsulates nitrogen so it doesn’t move around. The whole area of

creative solutions in manure management needs to be enhanced because it allows environmental protection when corn is not being grown.

111. Biochar – organic matter replacement.
112. Biochar is separate from traditional sources of soil carbon amendments. It is long lived (thousands of years as opposed to individual years) and has less affect on soil tilth.
113. Nitrogen inhibitors will also have a role.
114. Nitrogen degradation inhibitors and other nutrient stabilizers are being developed.
115. Nitrogen recovery and recycling.
116. Nitrogen fixation.
117. Encapsulating nitrogen.
118. Cover crop technology.
119. Breed living mulches.
120. Breed living mulches that allow no till between rows and grow well with corn.
121. Delayed emergence cover crops—coated seeds; low light tolerance; non-competitive at time of emergence; effective use of strip-tillage or strip herbicides to create planting zones, management guidelines.
122. We need to develop perennial species that can live in the corn crop without reducing yield that can provide roots in the soil to both stabilize soil movement, capture carbon, control wheel traffic, and increase water infiltration.
123. Obviously these mulches must not reduce yield of the primary crop.
124. Bigger and more robust crop rotations.
125. Strip intercropping?
126. Do you mean longer crop rotations with more diverse crops (perhaps including close-seeded and/or legume crops)?
127. There are many options to improve nitrogen management.....most require additional technology or management and increasing the risk of yield loss....and farmers are not compensated to do a better job of managing N closer to crop needs.
128. Economics and logistics of cover crops are not figured out yet.
129. If nitrogen prices would rapidly increase, cover crops become more viable.
130. Economic incentive for lower life cycle GHG corn could speed adoption
131. Landscape-scale management.
132. Develop a series of systems research sites where multiple factors are investigated simultaneously. Start with characterization of soil variability and hydrology. Select diverse mixture of feedstock resources so that high-yield corn yields can be pursued because there is greater buffer area where nutrient leaks can be captured without environmental degradation.
133. And develop system models that can be optimized using real-time data.
134. Making sure we monitor impact of management approaches so they can be optimized over time based on experience and environment/technology changes.
135. Need measures that allow us to monitor true soil and environmental impacts.
136. Collection of corn residue from directly off the back of the combine or in a second pass fashion. What other equipment technologies are available to reduce the time it takes while increasing yield all while keeping the cost in check.

137. Beyond collection residue storage solutions must be worked out.

138. We need to have variable-rate biomass collection technology.

139. There is a solution adoption issue (education) with residue removal. Producers need to know “how much and in what fashion before I start getting in trouble with environmental decline?”

140. About 10% of a watershed can be devoted to a wetland capture surface runoff and tile drainage. Wetlands would aid in flood control, reduce stream volumes, aid in erosion control, and improve water quality.

141. Agreed, but are we collectively willing to fund/compensate landowners for this?

142. Proper incentive structures need to be developed to improve sustainability as we move toward utilizing residues(at least temporarily).

143. Reliable models need to be developed.

144. Sustainability standards endorsed thru government policy and farm organizations.

145. Develop metrics, attach incentives, and farmers will manage to the metric.

146. A model to take into consideration: how much residue can I remove and in what yield zones. At what point to environmentalist yell at me for taking off too much residue? How much NPK am I going to have to put back on to compensate for what I took off.

147. Society may require changes and dealing with external costs of production....likely to appear first as water quality metrics.

148. Implementation as suggested requires some sort of value be applied to “environmental services.” Who pays for this and how? Is the answer always “the government”?

149. Risk analysis tools needed.

150. May be a role for on-farm pre-processing.

151. I continue to suggest that pre-processing of biomass for fuel may bring back the harvestore.

152. Need valid base lines.

153. The consolidation of farm operations must be considered....fewer farm operators controlling large acreages will involve more technology to improve logistics, remote data access and work order processing.

154. Other variables that effect yield other than residue removal - moisture, weather, nutrients, etc.

155. Management practices.

156. We come from 50 years of management for grain removal. Management is important–you really have to know your land, invest in soil test and characterization. Stover removal would be a new management practice that producers do not understand as well. Financial risk is high if you don’t know what you’re doing.

157. Need to understand and manage nutrients.

158. Could be a positive.

159. Can be positive or negative effects depending on seasonal weather patterns and management decisions.

160. Great concern over the longer-term impacts…some areas NW of Des Moines IA have been removing/baling corn stalks for years, and are beginning to see negative impacts on grain yield.

161. Can also be positive: Better early season vigor, more uniform germination, warmer soil, and reduce tillage in corn/corn plantings. Need to understand and manage nutrients.

162. Will residue collection slow my grain harvest???

163. Convenience during a busy time of year is important.

164. Impacts of weather on harvest window.

165. How does the cost of the biomass play in the business model of the end user (ethanol plant).

166. If this isn't solved, there is no long-term business. The answer isn't (or shouldn't be) more government money. The economics must make sense or this isn't a business.
167. Could we invest in higher quality residue from a breeders' perspective.
168. Lack of focus on Quality improvement of the residue.
169. Not all stover is the same in terms of processing efficacy. Moisture, degradability, plants parts are important.
170. Are some parts of stover more valuable than other? upper portion may be more valuable because of water content, soil contamination - if you leave lower portion, maybe you meet the needs of soil; cob can be pulled off with hardly any impact.
171. Lack of knowledge about field conditions or capabilities for new technologies including lack of qualified labor to run equipment.
172. Lack of on farm affordable preprocessing technology Densification and stability to allow for longer term storage, To prevent quality degradation and other storage losses, Time for producers to handle stover harvest in addition to grain in limited timeframe for Midwestern harvest.
173. Need to know characterization of fields before moving into a new management scheme – residue nutrient composition; most managers not familiar with extra nutrient removal associated with residues.
174. Again, it likely requires new technology to harvest variable amounts of biomass per unit area and spatially document actual removal.
175. Densification and stability to allow for longer term storage.
176. To prevent quality degradation and other storage losses.
177. Demand for the product and distance to location of final use.
178. Transportation Costs - Volume vs. Value and storage logistics Further processing to allow for densification and ease of transport and material losses during storage.
179. Delayed harvest resulted in detectable lower quality residue in 2008 data from Iowa.
180. Risk management.
181. Contingency planning.
182. There is a big need for crop insurance; on-farm storage fire risk; what are consequences for not delivering on contract; how to biorefineries replace undelivered product?
183. Lack of crop and liability insurance.
184. Impacts of weather on harvest window and quality.
185. Also impact of weather on quality (year effect on stover composition).
186. Time for producers to handle stover harvest in addition to grain in limited timeframe for Midwestern harvest.
187. Lack of qualified labor during harvest period.
188. Reduce the cost of collection equipment.
189. Improve the efficiency of collection equipment.
190. Give lots of equipment options to farmers to choose what makes cents for them.
191. How does the cost of the biomass play in the business model of the end user (ethanol plant).
192. If this isn't solved, there is no long term business. The answer isn't (or shouldn't be) more government money. The economics must make sense or this isn't a business.
193. There are many "obvious" solutions that can be implemented IF there is a viable market. The first step is to start a viable business, even if it's relatively limited.
194. Need a long term demand for the biomass feedstock.

195. [Increased grain yields with constant harvest index] This is likely to happen anyway....if there is an incentive to keep HI constant vs. just concentrating on grain yield, genetic suppliers will follow the money.

196. [Increased grain yields with constant harvest index] Little risk of this for the next ~ 10 years, but longer term this will depend on continued profitability in grain industry.

197. Data showed advantage to pulling residue off - because of weather conditions - weather variability. Corn-on-corn showed improvement, last time soy bean on corn was reduced.

198. Unless the producer receives a high enough return through the increased demand for corn, they will not invest in purchasing the new biotech technologies.

199. With grain and biomass as cash crops, we can increase revenue to the farm.

200. Economic incentive for lower life cycle GHG corn could speed adoption.

201. Duvick DN (1999) Heterosis: Feeding people and protecting natural resources. In JG Coors and S Pandey (ed) The Genetics and Exploitation of Heterosis in Crops. Crop Science Society of America, Inc., Madison WI. 19-29.

202. There are biotech solutions that could increase biomass, but for the most part they are being "shelved" because the focus is on increasing grain yield, not stover.

203. Improve the efficiency of collection equipment.

204. Give lots of equipment options to farmers to choose what makes cents for them.

205. Densification and stability to allow for longer term storage.

206. To prevent quality degradation and other storage losses.

207. BCAP is required to get the program started and get new equipment, that currently isn't available in the used equipment market, in the hands of farmers – required for the next 6 to 8 years.

208. This is intended to help start an industry, not as a long term welfare program. With a large and growing national debt relying on government handouts will not create a long term business.

209. BCAP needs to be extended long term.

210. Develop a financial risk management tool for residue production and harvesting.

211. Regarding better cost models, incorporate] return on investments for biomass collection with long term contracts.

212. Better cost models with reliable and realistic testing.

213. There are plenty of models. We need some real world data on actual costs to all parties, supply variation (quality and quantity). This needs to be of good enough quality to give growers, producers and bankers confidence to invest. Costs will reduce as we move down the learning curve.

214. Return on investments for biomass collection with long term contracts.

215. A good understanding of costs and benefits to producer - if you know the effects of all your management - putting it to cost models. Models need tested, so results can be presented to investors and build confidence.

216. Need long term contracts.

217. Typical of other biomass buyers (e.g., power generation).

218. Land tenure - now 60-80% absentee landowners - brings big change to landowners and lending institutions.

219. Farmers have to go to banker - what does he need to do to convince banker to lend; long-term guarantees by government; farmer can't bear all weather risk; farmer can't bear risk of program that is pulled after they've invested.

220. R&D on investment incentive programs.

221. Public and private investments are both needed. Education is crucial.

222. Must balance with denser populations - harder to have local livestock production.
223. Government policy – land.
224. CRP is mostly out west and is drought related.
225. Highly irrigated areas are not seeing rates of grain (having put much genetic effort here).
226. High-productivity lands will give you more stover than low productivity.
227. Look at % increase of dry land corn over last 20 years, now we have dry land corn all the way to Colorado due to genetics and management practices.
228. Marginal LCCs are getting yields - rates of gain for yield. We need more data analysis and increased understanding of phenotyping environments. Breeders have lots of room to build libraries of variety understanding.
229. Trend for corn acres will expand (according to demand) – it's been taking leaps, as long as price stays up, it will be expanded.
230. Corn is a bioprocessing plant, the most efficient energy capture crop there is.
231. There has been more technology put into corn to grow in these acres than any other crop.
232. Regarding the foundation for a bioeconomy going forward - corn is an anchor (maybe not as we imagined, but in other products).
233. Other countries are becoming more self-sufficient to grow their own grain - food security is more important now than energy security.
234. There will be world competition for corn and increased corn acres - seed sales indicate increase for next year, if fertilizer stays down; it is more profitable than any other crop.
235. We can't depend on export markets.
236. Corn ethanol production is capped. Will policy 15 B gal cap be raised?
237. Foodshed will shift with the cost of energy increase.
238. Livestock production is restricted here, which is a major market for corn. If livestock supply goes out of country, corn demand will drop.
239. We can develop high-value products from corn grain. We need to look at the stability of those other product markets.
240. Depending on price of oil, other product lines may come from corn: esters, hydrocarbons, etc.
241. Brazil will expand on soybean side.

WORKHOP 2 – HERBACEOUS ENERGY CROPS

Workshop Participants[a]*: Bill Belden, John Blanton, David Bransby, Cory Christensen, Fred Circle, Ken Goddard, Neal Gutterson, Stephen Long, Tom Lutgen, Vance Owens, Edward P. Richard Jr., and William Rooney*

Defining the Resource and Estimating Baselines

"Herbaceous Energy Crops" (HECs)

Herbaceous energy crops (HECs), crops grown specifically to produce some form of energy, are important for long-term sustainability of biofuels and bioenergy industries. HECs are generally fast-growing, high-yielding varieties of grassy biomass crops that have broad adaptability to growing conditions and land classes and can be incorporated into conventional farming operations. Some of the HECs under consideration for bioenergy production in the United States are *Panicum virgatum* (switchgrass), *Miscanthus* (miscanthus), mixed perennial grasses, *Saccharum* (energycane), and *Sorghum* (sorghum). These crops are at various stages of development, and there is still a great deal of work that can be done to determine the actual feasible role of each in a commodity-scale biomass market.

An overview of the current state of technology (SOT) for each of these HECs is included in this section. Commercial-scale production yield data for these crops is limited, and participants were asked, based on their expert understanding of the current SOT, to estimate baseline yields for these crops. Participants were instructed to provide estimates only on crops and resource zones they were knowledgeable about. The baseline estimates are summarized as ranges in Table 2-1 (dry ton/ac) for the different crops and zones. For discussion manageability, the zones were combined and adapted from the USDA's 20 land resource regions (Figure 2-1). The estimated baselines are also shown individually by crop in Figures 2-3,

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a. Workshop participants contributed the content of the report through survey answers and in-workshop comments. Individual participants are responsible for only the opinions and data they provided. Workshop report editors are responsible for assimilation of workshop data and participant comments in this summary.

2-5, 2-7, 2-9, and 2-11. Workshop participants acknowledged the difficulty of making accurate estimations from areas with such variety in land resource and suitability class, and they were asked to base their estimates on their understanding of the areas of each zone that were most suitable for the particular crop.

Table 2-1. Currently achievable HEC yields agreed upon by participants (dry tons per acre) for each land resource zone shown in Figure 2-1.

	Switchgrass	Miscanthus	Sorghum	Mixed Grasses	Energycane[1]	Sorghum
Region 1	5–10	2–16	6–12	0.5–5	0–12	6–12
Region 2	5–12	4–16	8–14	5–12	10–14	8–14
Region 3	3–8	4–16	9–13	3–8	0	9–13
Region 4	2–6	2–12	0–8	2–6	0	0–8
Region 5	2–6	1–5	0–6	2–6	0	0–6
Region 6	3–13	2–15	8–9	3–13	7–8	8–9
Region 7		10–16			(coast 10–16)	

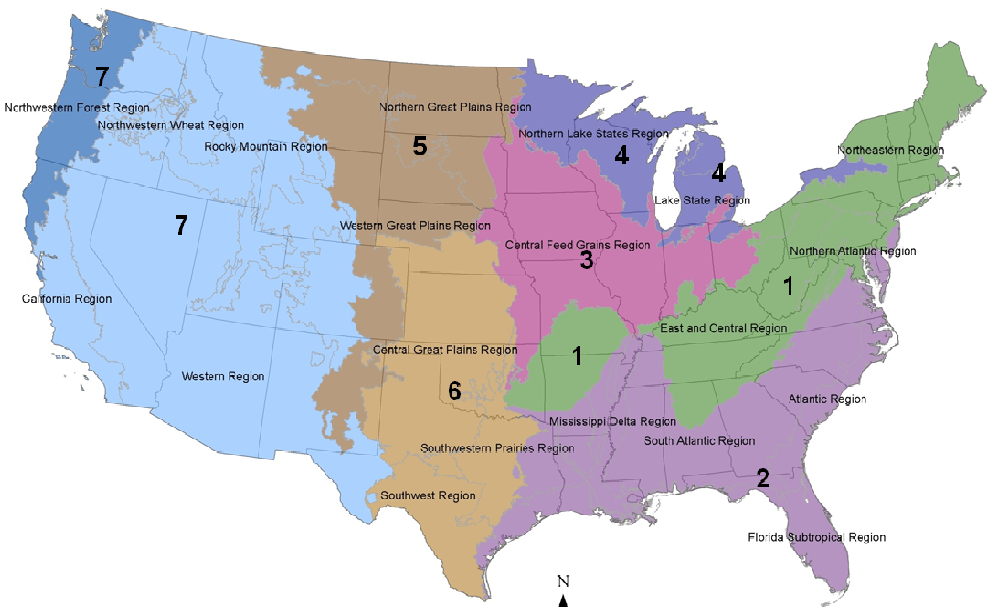

Figure 2-1. Land resource regions used to estimate current yields of HECS (adapted from USDA-NRCS [2006]).[b]

While there is undoubtedly a lot of potential for genetic improvement of perennial HECs, the process of new variety breeding, selection, and trialing is relatively slow compared with annual species like corn and sorghum. Varieties of switchgrass, sugarcane (and by inference, energycane), and other grasses are typically well adapted to a relatively narrow range of environmental conditions (i.e., climate and geography), and different varieties typically perform better in some environments than in others. Development of many varieties of each species will be required to get the best possible production performance across the breadth of available U.S. environments.

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b. USDA-NRCS (2006) Land Resource Regions and Major Land Resource Areas of the United States, the Caribbean, and the Pacific Rim, USDA Agriculture Handbook 296.

Switchgrass

Perennial herbaceous species such as switchgrass have not yet been extensively developed for their yield potential, and significant potential for yield improvement is thought to exist in the natural gene pool. There are barriers to overcome before developmental strides can be made for switchgrass. Genetic improvement of switchgrass using traditional genetic breeding and selection techniques is fundamentally different from corn, sorghum, and other hybrid variety systems. No highly inbred (i.e., homozygous at most genetic loci) varieties of switchgrass currently exist, as the species has evolved as an obligate out-crosser, and it is extremely difficult to self individuals. Without inbred varieties, it is impossible to generate true hybrid varieties. Moreover, the existence of heterotic groups within this species is not yet well documented, and this will be needed to justify development of hybrid varieties in the first place.

Figure 2-2. Switchgrass is a native warm-season perennial grass that can thrive in a variety of climatic conditions, growing seasons, soil types, and land classes. It can be grown on land that is not suitable for row crop production in either conventional tillage or no-till production systems.[2] (Photo courtesy of David Bransby, Auburn University)

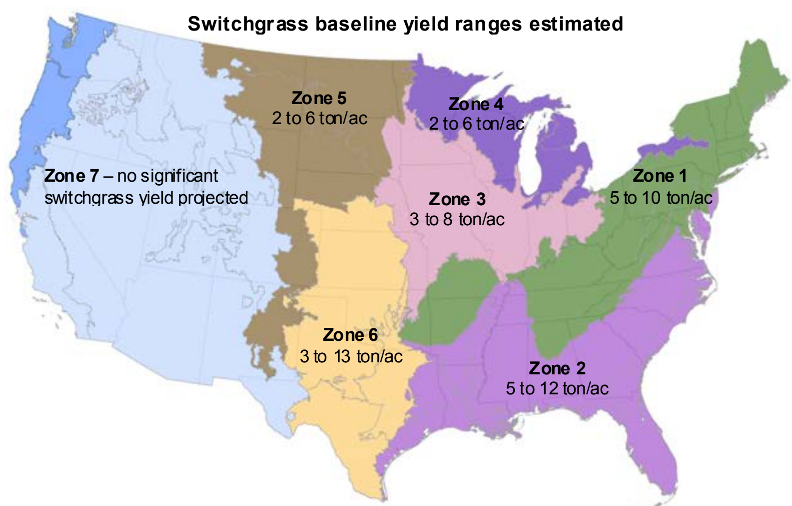

Figure 2-3.Estimated switchgrass baseline yields.[c]

Hybrid development time is another significant challenge. Performance improvements in switchgrass are usually measured at a population level, where a group of genetically distinct individuals in a progeny population are assessed relative to the performance of a check variety, also made up of genetically distinct individuals. At least 3 years of progeny testing are required to verify the performance characteristics of a new switchgrass variety. Initial field trials are typically followed by a series of competitive field trials across wider geography (another 3+ years). Scale-up of seed production in preparation for commercial sales to producers and seed certification processes to justify marketing the new variety distinct from its predecessors must also occur, and even if these are performed in parallel with wide geography trials, 8 to 10 years are required to develop a new switchgrass variety. Once new varieties start emerging from a breeding program, further improved varieties could probably be released on a much more frequent basis. Several public breeding programs are already at this stage.

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[c] Estimates based on participants' understanding of the areas of each region that were most suitable for the crop in question. Participants were asked to only provide input on regions and crops they were familiar with.

Miscanthus

The single, clonal variety of miscanthus that has captured the imagination of many scientists and business people in the bioenergy community, *Miscanthus x giganteus*, is a sterile triploid hybrid resulting most likely from a cross between tetraploid and diploid parents (Figure 2-4). As a result, it must be propagated vegetatively. This is typically accomplished using pieces of the rhizome, which must be excavated from a well-established stand in order to establish more acreage. This is a prohibitively expensive process that results in the production of a perishable product that can only be stored for a limited time before it loses viability. Clearly, it would be advantageous to develop seeded varieties of miscanthus. However, once planted, rhizome pieces are generally quite vigorous, and unless planted too late in the season, a good stand is fairly easy to establish.

Figure 2-4. Miscanthus is a tall perennial grass that is easy to grow, requires few inputs—particularly low nitrogen—and relatively little water, and produces a feedstock with low water content (15% typically at harvest) and ash content. Miscanthus can be grown on lands not suitable for row-crop production, producing a strong cane-like stem, and recapturing most of its nutrients underground at year-end before the harvest.[2] *(Photo courtesy of Mendel Biotechnology)*

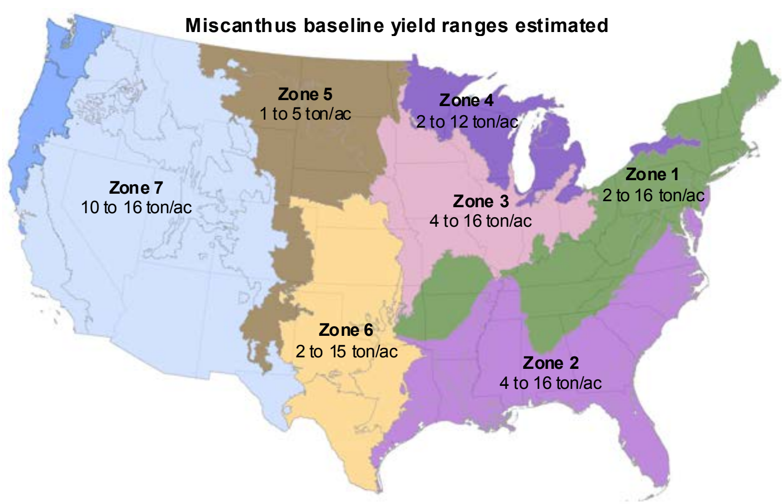

Figure 2-5. Estimated miscanthus baseline yields.[d]

Much like sugarcane and energycane, the seeds of miscanthus are extremely small and do not carry much energy reserve for establishment. As a result, they must be planted under extremely favorable conditions to ensure a good stand. Thus, a larger seed would be a great advantage.

In a vegetatively propagated crop like *M. x giganteus*, every plant is genetically identical, and all plants in a field usually perform quite similarly. Unless a viable hybrid breeding strategy can be devised for miscanthus, a seeded crop resulting from a cross between two (or more) parents would result in a field of genetically diverse individuals, and the performance of those individuals would be widely disparate across a field. A hybrid breeding strategy for miscanthus, which must take advantage of a heterotic "kick," would result in hybrid seed that are genetically very similar and would be expected to produce plants that perform fairly uniformly across a field. It is not clear whether a hybrid strategy can work in miscanthus.

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[d] Baseline yield estimates based on participants' understanding of the areas of each region that were most suitable for the crop in question. Participants were asked to only provide input on regions and crops they were familiar with.

Mixed Perennial Grasses

It is difficult to discuss enhancing the performance of a mixed species crop from the point of view of genetic improvement. Each species in a mixture would typically require its own breeding program to assess progress toward increased yield in that species (Big Bluestem shown in Figure 2-6). After selection of improved varieties for each species in separate breeding programs, new varieties could be combined in various proportions and assessed as mixed species populations relative to benchmark mixture(s) of the same set of species over a period of years across broad geographic and climatic conditions. Because these improved varieties will interact with each other in mixed populations, there is no guarantee that genetic improvements observed in pure stands will be evident in a mixed population planting. Moreover, the cost of these several breeding programs may be prohibitive. Similarly, genetic engineering of mixed species crops also would be extremely resource-intensive, and improvements documented in pure stands may not carry through in mixed populations.

Because of these complexities, it may be more promising to pursue performance improvements by concentrating on agronomic technologies and management practices (including capitalizing on the benefits inherent in polyculture cropping) to address challenges in (1) establishment, (2) nutrient- and water-use efficiency, (3) disease and pest stressors, and (4) harvesting and densification equipment performance and efficiency issues that will arise when handling polyculture crops.

Figure 2-6. Mixed perennial grasses refer to diverse mixtures of native perennial grasses (Big Bluestem shown). Some studies indicate that mixtures of prairie grass planted on degraded agricultural land can produce more bioenergy than the same land planted with various single species. Other work suggests that monocultures or mixtures work best if managed at a higher level. (Photo courtesy of Ernst Conservation Seeds)

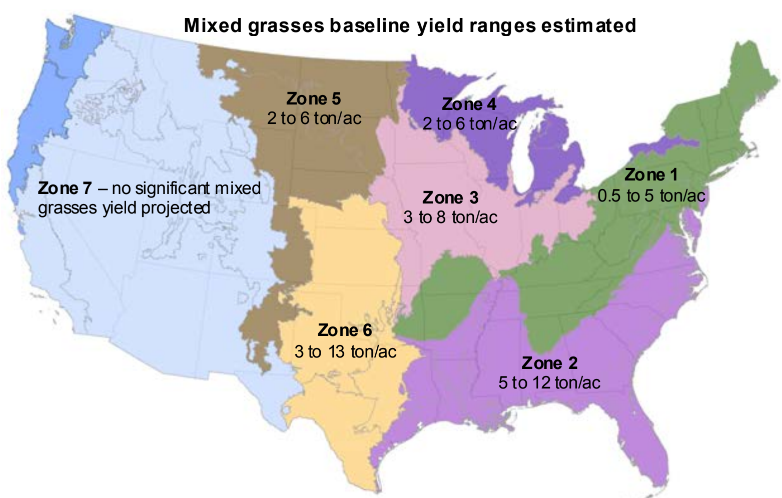

Figure 2-7. Estimated mixed perennial grasses baseline yields.[e]

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[e] Baseline yield estimates based on participants' understanding of the areas of each region that were most suitable for the crop in question. Participants were asked to only provide input on regions and crops they were familiar with.

Energycane

Energycane, a new perennial herbaceous crop (Figure 2-8), has not yet been extensively developed for its yield potential. Even though sugarcane has been subjected to centuries of breeding and selection for high biomass yield, high soluble sugar content, and low fiber content, energycane varieties are generally perceived as low-sugar, high-fiber varieties. Thus, desirable energycane clones typically would be destroyed after evaluation in a sugarcane breeding program.

Energycane, like sugarcane, is derived from a combination of tropical species, and therefore is restricted in its growing range in the United States. Though less than 1 million acres of sugarcane currently is grown in the United States (i.e., in southern FL, southern LA, southern TX, and Hawaii), this is primarily restricted by Federal quotas on U.S. sugar production. Sugarcane is currently produced only on acres that provide the best economic return to the farmers and processors, but it is clear from historical records that sugarcane can be grown much more widely than it currently is in the United States. Energycane may provide a profitable crop for farmers to grow that would perform well on marginal sugarcane acres, and even outside traditional sugarcane growing regions. The USDA-ARS and others are actively breeding and selecting new energycane varieties.

Figure 2-8. Energycane refers to sugarcane hybrids that are high in fiber and low in sugar. It is a tropical perennial grass that can be grown in the southern United States, and in field trials has outperformed sugarcane in drought conditions, on marginal land, in cooler environments, and with fewer inputs. (Photo courtesy of Ed Richard, USDA-ARS)

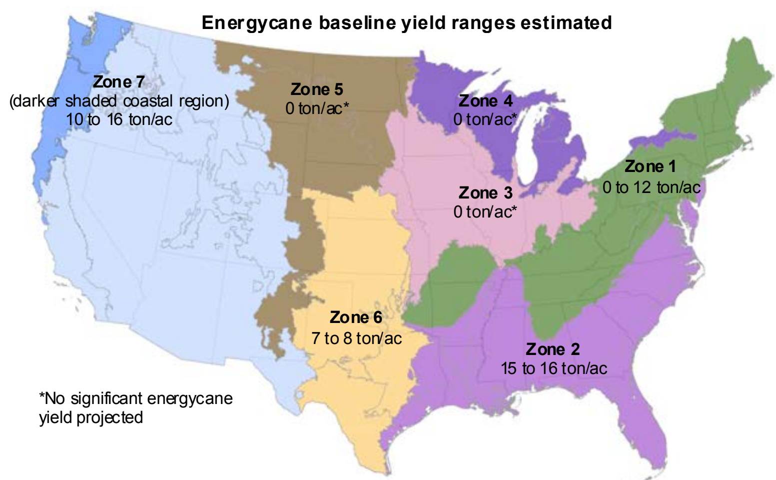

Figure 2-9. Estimated energycane baseline yields.[f]

[f] Estimates based on participants' understanding of the areas of each region that were most suitable for the crop in question. Participants were asked to only provide input on regions and crops they were familiar with.

Sorghum

There are four main types of sorghum known today: grain, sweet, forage, and high-biomass. The grain types have undergone substantial breeding and selection efforts to increase grain yield. Commercial grain sorghum varieties are typically short with a large seed head and a high harvest index (similar to corn). Sweet sorghum tends to deposit most of its photosynthate as sucrose and fiber in the stem, but does generally produce a modest amount of seed. Because of the rather low seed set, the harvest index is typically low. Sweet sorghum has not been the focus of much attention from U.S. plant breeders until very recently. Texas A&M University is actively pursuing improvement of sweet varieties, in collaboration with Ceres, Inc.

Figure 2-10. In many areas of the United States, high-biomass sorghum can be produced as a quick-growing annual. High-biomass sorghum uses water and inputs efficiently, has robust establishment characteristics, and can be produced on lands considered marginal for other crops. (Photo courtesy of Blair Fannin, Texas AgriLife Research)

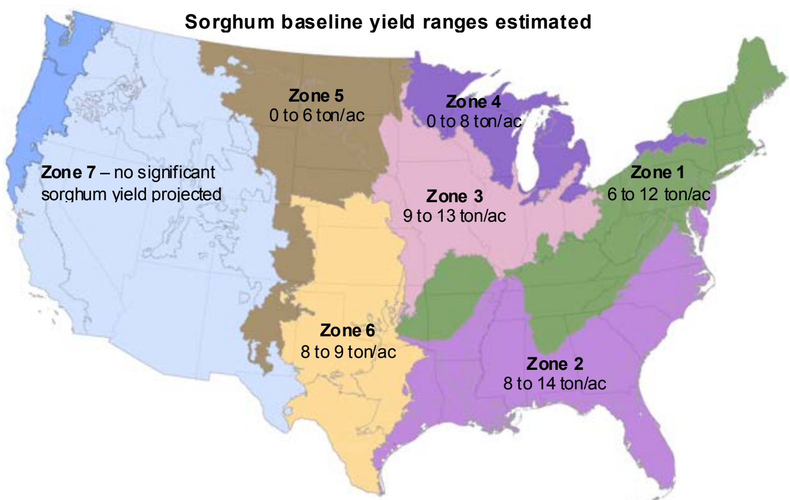

Figure 2-11. Estimated sorghum baseline yields.[g]

Forage types have also been subjected to a significant amount of breeding, but these are typically harvested green, either before flowering and seed set, or while seeds are still developing. The main concentration for improvement of forage sorghum varieties is biomass yield and palatability for cattle.

High-biomass sorghums are a special subset of the forage types that are bred not to flower, and an example is shown in Figure 2-10. These photoperiod-insensitive varieties do not enter a reproductive phase until day length decreases to less than 12 hours, which does not occur in the Northern hemisphere until after the fall equinox. The result is that by the time the plant transitions from vegetative to reproductive phase, the climate is changing rapidly and the plants typically undergo a freeze before seeds can even set, much less mature. This obviously necessitates a green harvest, as no senescence process will occur prior to freezing. The high-biomass types are also the subject of a very active breeding program at Texas A&M University in collaboration with Ceres, Inc. Mendel is also collaborating with MMR Genetics and Richardson Seeds to develop and produce improved bioenergy varieties of sorghum.

Sorghum breeding is analogous to corn breeding, in that it is an inbred-hybrid system. Highly inbred parent lines are crossed with each other to produce a hybrid variety that has much higher yield than either of its parents. Fairly well understood genetic systems for flowering time and dwarfing/gigantism are exploited to extend or shorten the vegetative phase of growth and the overall size of the plant, respectively. These systems are also becoming fairly well characterized at a molecular level. The sorghum genome has also recently been sequenced and will provide a resource for breeders of other grass species.

[g] Estimates based on participants' understanding of the areas of each region that were most suitable for the crop in question. Participants were asked to only provide input on regions and crops they were familiar with.

Alternate HYS Assumption Discussions

Workshop participants were asked to discuss R&D currently underway to improve HEC production yields and to what extent they believed future production improvements could be realized to support a high-yield biomass production scenario. The alternate HYS assumptions are shown in Table 2-2.

The scope of the alternate HYS assumption discussions focused on how development of genetic potential, biotechnology, and innovations in engineering and management could be leveraged to optimize yield with minimum inputs and sustained soil productivity.

Table 2-2. Workshop 2 – Herbaceous Energy Crops alternate HYS assumptions.

Discussion	Alternate Assumption
Yield	Average dedicated herbaceous energy crop yields will increase relative to current varieties (perennial varieties: switchgrass, miscanthus, mixed perennial grasses, and energycane; annual variety: sorghum).
Environmental Sustainability	The rate of adoption of herbaceous crop plantation management sustainability practices will exceed projections, and innovative new strategies will emerge, both leading to increased herbaceous biomass crop planting rates (i.e., acres) and yields, while maintaining or improving environmental quality.
Economic Viability	Overall economic conditions are met that incentivize producers to participate in herbaceous energy crop production.
Land Use	Land for dedicated herbaceous energy crops will come from existing cropland, pasturelands, and rangelands.
Other Technology/Policy Advances	Other technologies, research initiatives, and policies that will impact future herbaceous energy crop production are identified.

2.1 Alternate HYS Assumption – HEC Yield

Average dedicated HEC yields will increase relative to current varieties (perennial varieties: switchgrass, miscanthus, mixed perennial grasses, and energycane; annual variety: sorghum).

The objective of the first alternate assumption discussion was to identify the issues constraining and supporting the HYS and project the likely rate of yield increase percentage that could be realized with genetic advancements and management innovations on the horizon. The discussion focus was to assess what increased yields are technically possible with genetic advancements and management innovations, thus market drivers, supply/demand influences, and other economic reactions were excluded from the yield potential discussion and explored separately.

Limiting Factors

Participants identified a number of barriers, or "limiting factors," constraining HEC yields and ranked them from greatest to least impact on yield. Limiting factors that are common across crop types are discussed first and are followed by species-specific limiting factors.

Limiting Factors Common to All Crop Types

Participants discussed a number of common barriers to the development of HECs. These barriers apply particularly to the perennials of interest for this workshop (switchgrass, miscanthus, mixed grasses, and energycane). Historically, switchgrass has been the perennial HEC of focus. As a result, research on mixed perennial grasses is not very comprehensive[3] and R&D of higher yielding alternatives like energycane and miscanthus has been limited.[4] Relative to more developed annual crops like rice or even sorghum (major feed/food crops), all of these perennials lack a well-characterized genome and established breeding systems.[5] As a result, background research into their agronomy, breeding systems, and environmental sustainability is limited.

For this reason, their genetic improvement as sustainable bioenergy crops has progressed slowly relative to more traditional crops.[6,7] This has slowed the development of bioenergy crop cultivars with improved nutrient-use efficiency,[8] predictability of emergence during plant establishment,[9] herbicide tolerance,[10] tolerance to disease and insect pests,[11] and water-use efficiency.[12] Data is also lacking regarding the potential adaptation of these crops for expansion into geographic regions throughout the United States.[13]

Top ten limiting factors that impact yield (ranked in order of greatest to least impact on the high-yield scenario)

1. Limited background research into the agronomy, breeding systems, and environmental sustainability of these crops, relative to our major feed/food crops.
2. Lack of existing markets for all bioenergy crops
3. Limited producer experience with HEC production systems
4. Lack of field-scale understanding of nutrient amendment needs for HEC crops
5. Unreliable establishment success
6. Slow pace of genetic improvement
7. Lack of herbicide labeling for HEC species and their effects on yield
8. Producer risk tolerance
9. Lack of comprehensive research on mixed perennial grasses (switchgrass has been the focus)
10. Lack of genome resources and genome understanding

There is a need for development and use of yield models to help in selection of the best bioenergy crops and cropping systems for production within given geographical regions.[14] There is also a need for better nitrogen fixation capabilities associated with these crops, which may include management strategies such as intercropping with nitrogen-fixing legumes[15] or engineering this trait into the crops. Although there is a substantial challenge and cost associated with engineering this trait into plants,[16] the potential benefits from plant-associated nitrogen-fixation would be a great benefit. Water-use efficiency is an also important plant attribute and is needed for viable yields of all these crops without irrigation in the west.[17,18,19,20,21,22,23]

Other barriers that were highly ranked by participants as impacting HYS included inadequate producer/management skills and production methods,[24] production risk tolerance,[25,26] lack of existing markets for all bioenergy crops,[27] and inadequate government support programs including financial support to build the infrastructure to deliver the biomass feedstock supply.[28,29]

Species-Specific Limiting Factors

Switchgrass

As a non-conventional crop, switchgrass lacks in its agronomy, breeding systems, and environmental sustainability knowledge base relative to our major feed/food crops. Its less-characterized genetics and genome relative to the sequenced genomes of sorghum, rice, and *Arabidopsis* has limited its improvement as a HEC.[30] There is plenty of opportunity to increase yields, but as with other perennials, the breeding cycle is long. Even though the annual gain in productivity may only be 2.5 to 3.0%, breeding efforts will increase germination efficiency, improve the yield of varieties, and improve insects/disease resistance.[31] Contributing to the slower rate of productivity gain is the limited number of switchgrass breeders,[32] but there are significant and comprehensive breeding programs being run by private industry and universities.[33]

Crop establishment is slow relative to annual crops, and there are a number of challenges to getting a good stand in the first year, such as seed size and weed management.[34] Switchgrass produces smaller seeds than mixed perennial grasses, energycane, and miscanthus, [35] and the small seed size presents significant difficulties. There is a lack of optimal production system technology for this small-seeded grass crop. They are more difficult to handle in mechanized planters, and their limited energy stores reduce seedling vigor. This is compounded by dormancy issues[36] that will require higher seeding rates.[37] Weed management is also a challenge as the crop is getting established, and herbicides need to be formulated and labeled appropriately for switchgrass.[38] There are other knowledge gaps that need to be understood and optimized to improve the predictability of plant emergence and establishment,[39] including seeding depth, seeding rates,[40,41] timing,[42] no-till practices,[43] and nutrient-use efficiency.[44] Another unknown is the impact that high concentrations of acres dedicated to one bioenergy species, such as switchgrass, will have on crop pests, diseases, and insect problems.[45]

Producers also need greater understanding of best management practices (BMPs) for switchgrass production to cost-effectively establish, produce, and manage switchgrass and other bioenergy crops.[46] University extension services could play a valuable role in educating producers.[47] Access to this information would help producers in dealing with issues ranging from optimization of production inputs to better management of feedstock supply system logistics.[48] The cost of production, competition for land resources for alternative crops, and access to biomass market are important considerations.[49,50] Because of the low economic returns anticipated during the establishment years,[51] the accurate modeling of production costs is critical for projecting potential risk and return on producer investment.[52]

Miscanthus

Like the other perennial bioenergy crops, knowledge of miscanthus' agronomy, breeding systems, and environmental sustainability is lacking in comparison with conventional feed/food crops. The lack of basic genomic information[53] and data from a range of relevant species is a challenge to its rapid development as an HEC, but this also presents a major opportunity for government to support and spur development of a high-tonnage HEC for the bioenergy industry.[54] Like other perennials, it has a long breeding cycle,[55] and government support for marker-assisted breeding systems and identification of genes for key yield traits could make a major impact on its yield.[56]

Miscanthus development as an HEC will require a well-characterized germplasm from a range of relevant species.[57] A majority of the work on miscanthus has been focused on a narrowly adapted single genotype. There is a need for information on a more broadly adapted miscanthus germplasm,[58] and industry may be in the best position to secure broader germplasm resources and develop and deploy new finished varieties.[59] The need for clonal vegetative propagation of *Miscanthus 'Giganteus'* results in the high cost of establishment of the crop[60] and challenges breeders in their quest for developing rapid varietal improvement cycles.[61] However, even with this limitation, established protocols have been developed in Europe, where several thousand acres are now planted.[62]

Although a seed production system is lacking for *Miscanthus 'Giganteus,'* there are significant advances occurring in development of seeded *Miscanthus spp*.[63,64] Finally, the lack of established weed control systems for miscanthus is a limitation to its establishment as a high yielding bioenergy crop.[65]

Mixed Perennial Grasses

Of all the potential energy crops discussed, mixed perennial grasses are the most lacking in applied research into their agronomy, breeding systems, and environmental sustainability relative to major feed/food crops. One of the largest barriers to the use of mixed perennial grasses as a commercially viable bioenergy crop is their relatively low yield.[66] However, in contrast to sorghum, mixed grasses can be grown on somewhat to quite marginal land.[67,68,69] This can potentially minimize establishment risk when growth variables are hard to predict, but it may be more limiting for some grasses in the mix than others.[70] As with switchgrass and other perennials, the breeding cycle for mixed perennial grasses is long, which delays the potential rate of yield improvement and possible annual rates of gain in productivity.[71] Another challenge is working with mixtures of seeds of different sizes, which makes uniform planting difficult.[72,73] Seed availability and cost are also barriers,[74] but these will improve as demand increases.[75]

Like switchgrass, mixed perennial grasses have similar establishment challenges[76]: the predictability of plant emergence is not optimized,[77] and potential producers have a very limited knowledge base to draw from regarding establishment, production, and management practices.[78]

Energycane

Energycane's lack of background research regarding best agronomic practices, breeding systems, and environmental sustainability can build on plant breeders' experience with sugarcane; however, current breeding programs are now limited to those states that grow sugarcane. In addition, these crop development programs are under-staffed, and like the other perennials, the breeding cycle is longer than that for annuals.[79] There is also a limited diversity of germplasm available for these programs, which drives the need for the collection of wild species and related genera for trait introgression by breeders.[80] Support is lacking but should be government sponsored[81] for the collection of this exotic germplasm in foreign countries where wild species of sugarcane and related genera such as *Miscanthus* and *Erianthus* are native species. Expansion of energycane production and breeding programs beyond the traditional cane growing areas also is needed.[82] Sustainable agronomic practices for producing energycane need to be developed for areas outside of traditional sugarcane production locations.[83,84]

Implementation of sustainable agronomic practices would benefit from a better understanding of the nutrient requirements for production on different types of soils and in more northerly growing environments.[85] Best feedstock logistic practices are also needed for simultaneously handling energycane lignocellulose and free sugars.[86] Technology development is needed for optimizing the collection and processing of feedstock water, sugars, and fiber components from this feedstock for biofuel production.[87] Finally, there is a need to educate growers in establishing and managing this perennial row crop.[88] Currently, growers lack experience with this new bioenergy crop and are reluctant to plant it because it requires a long-term commitment, particularly if grown on cropland.[89]

Sorghum

As a conventional annual grain and forage crop, sorghum has considerable background research into its agronomy and breeding systems relative to the other perennial herbaceous crops discussed at this workshop. Along with rice, it is one of the few grasses whose genome has been fully sequenced. This rich knowledge base can be applied directly to the development of a new photoperiod sensitive sorghum as an HEC. Because of its potential for outcrossing with Johnson grass (*Sorghum halepense*), which is considered a weed, there may be resistance from environmental advocacy organizations.[90] However, the development of photoperiod sensitive sorghum that does not flower within the latitudes of the United States, can restrict its outcrossing and thus make it a better candidate as a new HEC. Plant breeding experience with its grain and forage relatives, along with its sequenced genome and relatively better understood genetics, supports more rapid introgression and engineering of genes for biotic and abiotic stress tolerance,[91] nutrient-use efficiency,[92] and water-use efficiency. This is the case even though all of the C4 HECs being considered by the participants use water physiologically at the same rate.[93] However, as an annual, nutrients including nitrogen will not be recycled as they are for fall-harvested bioenergy perennials.[94] So, relative to the other perennial bioenergy crops, annual bioenergy sorghum will require a higher nitrogen input.[95] Other barriers to the development of sorghum as an HEC include the lack of efficient preprocessing and storage logistics methods and equipment for this high tonnage crop and the lack of market-driven outlets for producers who wish to participate in the biomass feedstock production.

Assumption Enablers

The limiting factors were used to brainstorm solutions, or "assumption enablers," that might support increased yields and the HYS assessment. Ideas were organized and ranked according to their potential to impact biomass yields. A broad range of promising approaches and needed advancements were suggested that fall under a number of different R&D and policy arenas.

1. Conduct agronomic research on seed rate, planting time, harvest time, etc.

Continued agronomic research of energy crops will help identify important sustainability and nutrient management issues. One method to address both issues is integration of a cover crop (such as legumes) to a feedstock production system, which improves soil productivity while potentially reducing nitrogen application requirements.[96]

2. Perform wider geographical side-by-side trials for statistically valid comparisons

Yield trials using best-in-class varieties should be conducted on land intended for energy crop growth on a regional basis as well as university plots.[97,98,99,100] Larger scale field trials are needed[101,102] as well as long-term trials to determine if the land is capable of producing consistent yields over time.[103] These trials would result in determining yield capability across different landscapes[104] and identification of higher yielding energy crops on a regional scale.[105] For example, conducting competitive yield trials would help determine how far north and west viable yields of miscanthus, energycane, and elephant grass can be achieved.[106,107,108] This provides an opportunity to determine the optimal mix of energy crops, soil and water conservation efforts, and wildlife diversity locally and regionally.[109,110,111] Improved genetics could also improve yields and increase regional diversity of an energy crop.[112]

A general lack of knowledge of regional characteristics, such as landscape and weather, makes it difficult to determine production capabilities of different regions.[113] Development of BMPs per crop by region should be completed to determine sustainable removal rates while optimizing extractable energy per acre.[114,115] Conducting side-by-side trial analysis is critical in development of BMPs,[116] but it should be noted that cost comparisons of BMPs do not translate across regions.[117] BMPs should include harvesting practices that use commercial technologies rather than hand-gathering to give more accurate cost analysis, yield, and feedstock characteristics.[118]

A complete cost analysis should be conducted from production to harvest of the energy crop as some crops have desirable attributes but are not commercially viable.[119] Biorefinery operators should be involved in the decision process to help determine if an HEC is feasible based on logistics and conversion efficiency.[120] Collaboration with national laboratories, universities, and industry would also be beneficial.[121]

3. Develop and implement long-term systematic crop improvement programs for each crop

Another enabler is the establishment of long-term systematic improvement programs for each crop. This includes the development of a government-sponsored R&D program where academic laboratories and government agencies develop genetic resources and collaborate with industry to produce enhanced crop varieties.[122] One method of enhancement is through heterosis, which might produce very large yield improvements in switchgrass, miscanthus, and energy cane.[123] Another promising method for yield improvement is through site- and timing-specific nutrient amendment and the use of feeder crops, such as N-fixing legumes.[124]

4. Improve seed for stand establishment

Seed enhancement is a common practice for improving establishment in many crops and should be considered for herbaceous energy crops.[125] Possible enhancements include seed size, seedling vigor, herbicide tolerance,[126] seed treatments, and applied coatings. Enhancements should address establishment issues through vegetative propagation[127] and N fixation of perennial grasses.[128]

5. Conduct research on weed control

Another enabler is additional research on weed control with the focus on the development of herbicide-resistant feedstocks.[129,130] Weed control is the most significant problem for stands during the establishment period.[131] By applying proper weed control measures during the establishment period along with starter nitrogen fertilizer, yields will substantially increase.[132] Research on weed control should be conducted through universities with insight provided by agricultural chemical companies, who understand the emerging market.[133] Beyond herbicide-resistant feedstocks, research should include studies on weed contamination when biofeedstocks are integrated into adjacent food crop areas[134] and the impact that weed contamination has on the production of biofuels.[135] As biofeedstock acreage increases, considerations for how disease and insects propagate through the stand also should be addressed.[136]

6. Exploit biotech traits to increase yield and efficiency of production, stress tolerance

Advancements in biotech traits allow for improved yields and durability beyond an energy crop's native region. There are many opportunities to leverage traits developed for major row crops to achieve improved performance in energy crops.[137,138] Flowering control could be used to help maximize harvestable biomass while limiting seed production. Known genomes could be leveraged in comparative genome approaches. [139] Genetic transformations might produce enhanced energy crops that can be grown in dryer climates[140] and improve stress tolerance to address sustainability issues.[141] Genetic transformation systems should be combined with improvement programs to provide an outlet for technology in improved varieties.[142] Research on molecular traits would also help in understanding the impact biotic and abiotic stresses have on plant development and would probably come from the commercial sector.[143] As yield improvements are achieved, there will be increased potential of crop lodging, so this also needs to be a consideration for research programs.[144]

7. Improve intrinsic N fixation

Some energy crops, such as miscanthus, have the ability to continuously produce high yields for many years with application of nitrogen. Understanding the endophytes involved in this trait and the plant's symbiotic relationship could lead to improvements in other grass crops[145] and possibly legumes.[146]

Projecting Future Yield Improvement

Participants discussed the yield potential for HECs through the identification of current barriers, potential solutions overcoming the barriers, and the likelihood of commercial-scale implementation if those barriers are overcome. Potential yield improvements (%) achievable by 2017, 2022, 2030, and 2050 were projected for each species.

Figure 2-12 shows the distribution of participants' individual projections for potential switchgrass yield improvement in Land Resource Regions 1 through 6 (from left to right at each time period). Reference lines indicate annual yield improvements of 1% as an assumed baseline rate of improvement (gray solid line) and 2 and 4% (gray dashed lines), which may be achievable as more effort and funding are applied to accelerate progress.

Similarly, Figures 2-13 and 2-14 show the distribution of participants' individual projections for potential miscanthus and mixed perennial grasses yield improvement (respectively) in Land Resource Regions 1 through 6.

Figures 2-15 and 2-16 show the distribution of participants' individual projections for potential energycane yield improvement in Regions 1, 2, and 6 and potential sorghum yield improvement in Regions 1, 2, 3, 5, and 6.

Tables 2-3 through 2-7 show the number of participants providing input and the rate of consensus for each crop, region, and time period.

Figure 2-12. In the near term, the density of projections is fairly evenly spread between 1 and 4% annual yield improvement. In the far term, projections range from 1 to 2% annual improvement.

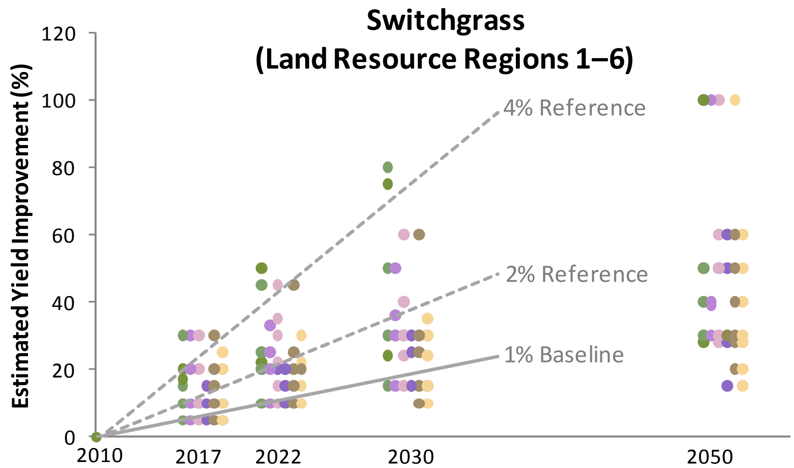

Table 2-3. Switchgrass – number of voters and voter consensus (VCC[h]) for each land resource region.

Land Resource	# of Voters	2017	2022	2030	2050
Land Resource Region 1	9	0.93	0.87	0.77	0.70
Land Resource Region 2	6	0.91	0.92	0.89	0.75
Land Resource Region 3	7	0.90	0.88	0.86	0.76
Land Resource Region 4	5	0.96	0.95	0.92	0.82
Land Resource Region 5	7	0.91	0.88	0.84	0.73

Figure 2-13. The density of projections for miscanthus appears in two trends, with the more conservative estimating 0.5 to 2% annual yield improvement and the more optimistic estimating greater than 4% annual yield improvement.

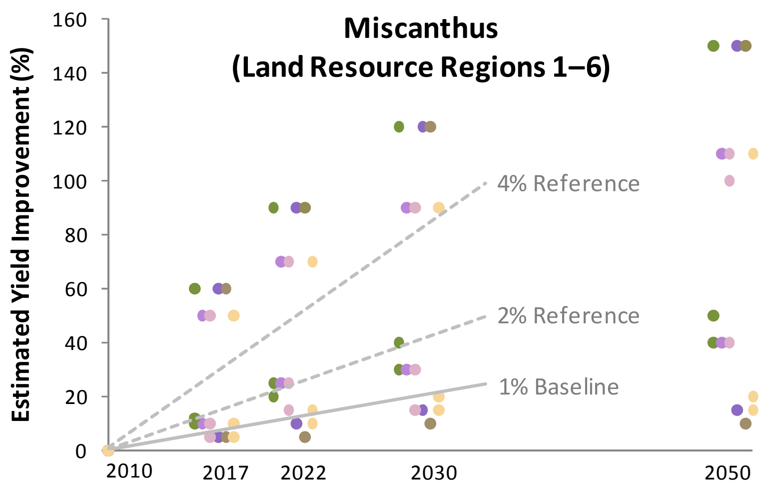

Table 2-4. Miscanthus – number of voters and voter consensus (VCC[h]) for Regions 1–6.

Consensus	# of Voters	2017	2022	2030	2050
Land Resource Region 1	3	0.72	0.61	0.51	0.39
Land Resource Region 2	2	0.72	0.68	0.58	0.51
Land Resource Region 3	3	0.75	0.71	0.60	0.62
Land Resource Region 4	2	0.67	0.43	0.26	0.05
Land Resource Region 5	2	0.61	0.40	0.22	0.01
Land Resource Region 6	3	0.75	0.67	0.58	0.47

[h] Ventana Coefficient of Consensus (VCC): the closer the rating is to 1.0, the greater the voter consensus.

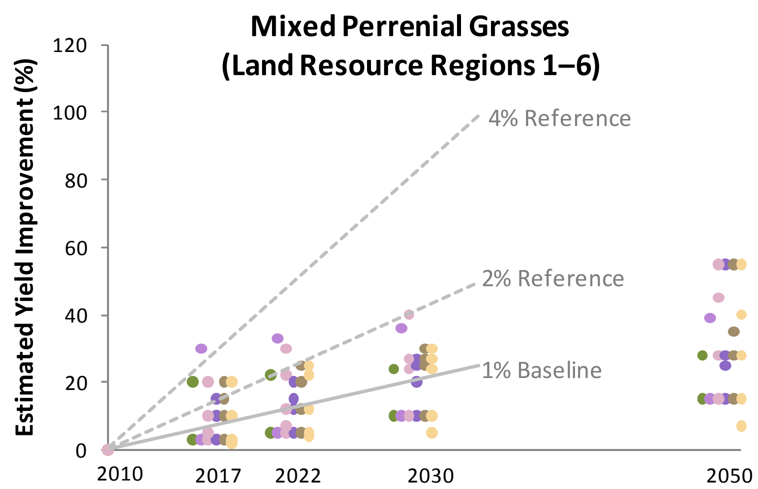

Figure 2-14. The density of projections for potential mixed perennial grasses yield improvement ranges between 0.5 and 2%.

Table 2-5. Mixed perennial grasses – number of voters and voter consensus (VCC[i]) for Regions 1–6.

Consensus	# of Voters	2017	2022	2030	2050
Land Resource Region 1	2	0.89	0.88	0.90	0.91
Land Resource Region 2	2	0.83	0.80	0.82	0.83
Land Resource Region 3	5	0.92	0.89	0.87	0.82
Land Resource Region 4	4	0.95	0.94	0.92	0.83
Land Resource Region 5	4	0.93	0.91	0.91	0.83
Land Resource Region 6	5	0.91	0.90	0.89	0.81

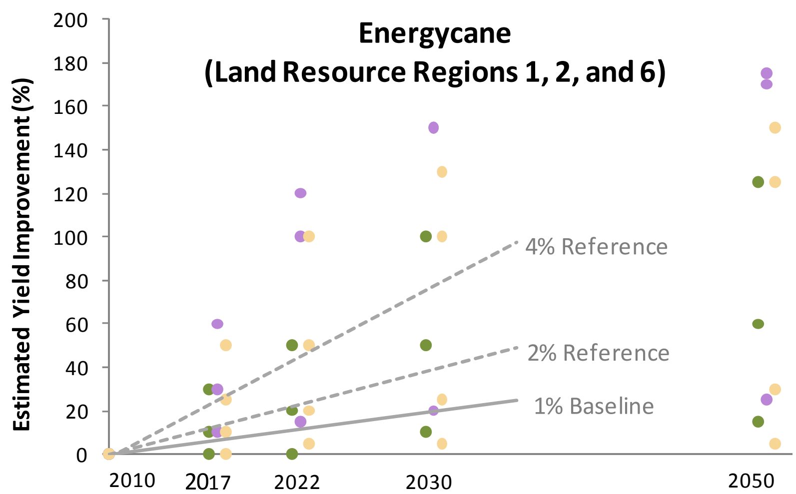

Figure 2-15. The density of projections for potential energycane yield improvement ranges broadly between 0 and much greater than 4%.

Table 2-6. Energycane – number of voters and voter consensus (VCC[i]) for Regions 1, 2, and 6.

Consensus	# of Voters	2017	2022	2030	2050
Land Resource Region 1	3	0.85	0.75	0.55	0.45
Land Resource Region 2	3	0.75	0.44	0.25	0.15
Land Resource Region 6	4	0.78	0.58	0.40	0.29

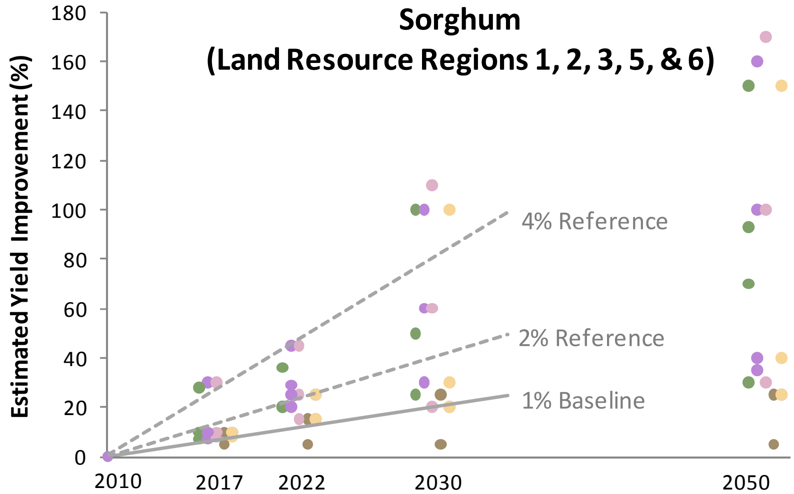

Figure 2-16. The density of projections for potential sorghum yield improvement ranges between 1 and 4% in the near term and between 1 and greater than 4% in the far term.

Table 2-7. Sorghum – number of voters and voter consensus (VCC[i]) for Regions 1, 2, 3, 5, and 6.

Consensus	# of Voters	2017	2022	2030	2050
Land Resource Region 1	4	0.90	0.92	0.69	0.50
Land Resource Region 2	4	0.89	0.89	0.67	0.41
Land Resource Region 3	4	0.90	0.87	0.60	0.34
Land Resource Region 5	2	0.96	0.93	0.89	0.86
Land Resource Region 6	4	0.99	0.94	0.61	0.40

2.2 Alternate HYS Assumption – Environmental Sustainability

The rate of adoption of HEC plantation management sustainability practices will exceed projections, and innovative new strategies will emerge, both leading to increased HEC planting rates (i.e., acres) and yields, while maintaining or improving environmental quality.

Limiting Factors and Assumption Enablers

Current baseline projections primarily consider the use of BMPs for herbaceous crops. A broader set of innovative management practices and technology could potentially address the factors limiting HEC production improvement rates while maintaining environmental quality. As part of the environmental sustainability alternate assumption discussion, participants were asked to identify the environmental barriers, or "limiting factors," constraining yield. The limiting factors were used to brainstorm solutions, or "assumption enablers," that might support environmental sustainability *and* increased HEC production. The assumption enablers and related suggestions are presented in this section in the order of greatest to least potential impact on the HYS.

1. Implement emerging concepts in management practices

There are several areas that can be addressed for improved soil and crop management practices. Tillage operations, such as the adoption of no-till agriculture,[147] provide a less soil disruptive approach, and while they apply primarily to annual species, they could also be used during the seeding year of perennials.[148] Along with tillage operations, crop rotation strategies, integrated cropping systems, cover crops, manure management, and weed and disease management,[149] have a considerable effect on soil erosion[150] and nutrient management within designated energy crop areas. One way to address all these issues is to develop planned production programs and systems and establish recommended production BMP's by region.[151] Studies should also be conducted to identify what the yield-limiting factors are across the different regions.[152] Participants also mentioned that improved control of grassy weeds[153] during the establishment period would allow for starter fertilizer applications and increased yields during the first year.

2. Minimize nitrogen use

Minimizing nitrogen[154] use requires defining the necessary amount of nitrogen that is needed to initiate an effective, energy crop plantation, and to understand the full energy impact over lifetime of that plantation.[155] Several options for minimizing nitrogen use were suggested, including incorporating legumes into crop rotations and monitoring its effects on yield,[156,157] studying nitrogen fixation of perennial grasses,[158] N-fixing microorganisms,[159] and the use of filter strips[160] to mitigate N run off and pollution of waterways.[161]

3. Minimize risk of new biomass crops becoming invasive or intercrossing

Introducing new biomass crops into foreign cropland creates the potential for the new crops to become invasive and overrun the native vegetation population. A strategy needs to be developed to ensure that new varieties of perennial energy crops being introduced to a new environment have a low potential for invading the area.[162,163] The strategy should be based on real-world experience and observations with the potential crops and not rely solely on model simulations.[164]

A concern was raised about the need to prevent inter-crossing of improved switchgrass and other prairie grasses with native prairie,[165] but some suggested that cross compatibility would only occur between switchgrass varieties and was unlikely between species.[166] There are genetic technologies that can be explored to prevent intercrossing with weedy relatives and transgene escape.[167] These can be combined with conventional strategies for biomass crops to reduce seed production.[168] The male sterility system can be manipulated to reduce/avoid gene flow,[169] and delayed flowering can be used to eliminate the reproductive phase of growth.[170,171,172] Species development program exit strategies also need to be developed to address invasive issues.[173]

4. Develop improved carbon sequestration and methods for indirect monitoring of carbon accumulation in soil

Participants identified improved carbon sequestration through root and rhizome development as a promising enabler.[174] In the future, growers will be able to produce aboveground carbon for energy as well as have the ability to "farm" belowground carbon as a means of income. This is a direct step to reduce atmospheric CO_2 through carbon negative cropping.[175] Actual measurement data of root and rhizome biomass would help document the below-ground carbon for harvest.[176] One suggestion for monitoring soil carbon accumulation in the soil[177] is through studies of prairie grass and other dedicated energy crops.[178] Crop development efforts might also include selection of lines that produce refractile litter.[179]

5. Develop planned production programs

Participants identified several options for developing planned production programs[180] for switchgrass. These options include rotations with mixed perennial grasses,[181] all energy crops,[182] and the development of a fallowing system where the effects on establishment and environment are documented.[183] It was also noted that yields increased when wheat follows hay or balage (silage in a bale) and ryegrass follows hay. These types of planting systems produce better stand, quicker germination, and reduced weeds.[184] Other weeds such as Tall fescue, among others, can be controlled in the fall by increased use of no-till.[185]

6. Implement landscape-scale management strategies

There is a need to explore the role of landscape diversity in meeting future biomass needs and conduct studies to identify yield-limiting factors across geographies.[186] Developing and implementing management strategies at the landscape scale is also a promising approach to sustainable HEC production. Landscape-scale management enables precise land-use planning to address soil erosion issues[187] as well as the ability to match various energy crops with ideal soil and landscape conditions to maximize production.[188] To support this, it would be desirable to have more than one viable bioenergy crop for each region.[189] Other suggestions for enabling landscape-scale management include the addition of legumes for the benefits they would have on forage mass[190] and dual-use opportunities for the beneficial effects they can have on the environment.[191]

7. Identify ways to manage changes in land use for energy crop production with minimal soil carbon loss

Changes in land use can release soil carbon, and it is important to minimize the amount of soil carbon lost during the land-use transitions as much as possible.[192] This can be addressed in a variety of ways. One method of accomplishing this is through improved sustainability practices. For example, in the case of converting a pasture to a high yield energy crop, applying a herbicide treatment rather than performing a tillage operation limits the disruption of the soil. Removal of animal residue from the pasture prior to the herbicide treatment could potentially be part of the conversion process.[193]

8. Conduct studies to quantify benefits of environmental services

A number of participants expressed that farmers who grow energy crops and engage in conservation practices should be compensated for their efforts. Farmers should be provided some form of financial incentive for their indirect goods and services.[194] Studies need to be conducted to quantify the benefits of those services.[195] Those who make an effort to improve sustainability could be rewarded through a *payment-for-ecosystem-services*-type program, similar to programs conducted by NRCS.[196] Another form of incentive would be to distribute CRP-type payments for conservation practices that allow the harvest of biomass.[197] Efforts to develop these initiatives should come through collaborative efforts among government agencies such as DOE, NRCS, and USDA.[198]

9. Leverage ecosystem services provided by perennial crops for environmental sustainability

Perennial crops offer several advantages over annual feedstocks when it comes to soil sustainability and nutrient management. Perennial crops improve soil carbon[199] as well as the ability to maximize nutrient recycling.[200] Nutrient mobilization late in the year is a key attribute of perennials, and to maximize the value of perennials, late-season harvesting using a single-pass harvesting system is ideal.[201] Perennials and filter strips also provide a means to limit the amount of soil erosion that occurs in certain regions.[202] We also need to consider that while leaving behind some residue after harvest can prevent erosion issues, it may hinder development of the following year's crop.[203]

10. Develop an integrated pest management (IPM) program for switchgrass and mixed perennial grasses

IPM program development for switchgrass and mixed perennial grass cropping systems strive to reduce the use of pesticides while still managing pest populations. Implementation of IPM systems should be considered for all cropping systems.[204,205,206] In terms of pest management in general, considerations must be made not only for the feedstock but also the adjacent crops.[207] This includes disease that can spread without proper pest management.[208] Biotechnology approaches may also be effective in pest management while reducing the use of pesticides. One example to support this is RR corn ("Roundup Ready" genetically engineered to permit herbicide application without killing crop) and Bt corn (genetically altered to express the bacterial *Bacillus thuringiensis* [Bt] toxin), which have been shown to reduce use of chemicals and benefit the environment in terms of beneficial insect species.[209]

11. Identify moisture conservation practices that would reduce the need for irrigation

Supplemental irrigation or deficit irrigation strategies are needed to optimize biomass yield on reduced water input.[210]

12. Develop management practices and technology for harvesting perennials

Determining when to harvest is especially important when commercial growers are asked to harvest early.[211] Under commercial circumstances, consideration of when to harvest should be based on the age of the perennial because; for example, it is unlikely that a 7-year-old stand of switchgrass will yield as much as a 4-year stand.[212] Determining harvest strategies is important for maintaining the health of the stands. Identifying the ideal time to harvest and how often to harvest are critical decisions that impact the life and yield of the stands. [213,214] Determining the proper amount of residue to leave in the field is also important for soil erosion and nutrient recycling.[215]

2.3 Alternate HYS Assumption – Economic Viability

Overall economic conditions are met that incentivize producers to participate in herbaceous energy crop production.

Establishing biomass as a commodity is an economically complex undertaking and involves interactions throughout the entire supply chain, from providing incentive for growers to produce feedstocks, through conversion and distribution of the final product. The current economics behind producing dedicated HECs do not provide much incentive for producers to participate, as there is currently no commercial biorefining industry in the United States. The lack of participation of producers results in significant risk to biorefiners and will ultimately undermine the establishment of a bioenergy industry. There is a very real *chicken-and-egg* problem: biorefiners (and financial backers) will not invest in a refinery unless a secure, long-term feedstock supply will be available at start-up, and producers will not plant biomass crops until biorefiners commit to building a refinery in their vicinity.

These activities need to be coordinated somehow, and government incentives could play a significant role here. The delivery of a fully functional Biomass Crop Assistance Program (BCAP) in 2010 may be the right mechanism to achieve this.

Limiting Factors and Assumption Enablers

As part of the alternate assumption discussion of Economic Viability, participants were asked to identify the economics-related barriers, or "limiting factors," that prevent producers from becoming actively engaged in dedicated herbaceous energy crop production and selling, and thus constrain establishment of a commodity-scale market for herbaceous energy crops.

The limiting factors were used to brainstorm solutions, or "assumption enablers," that might support the HYS. The assumption enablers and related suggestions are presented in this section in the order of greatest to least potential impact on viability of a bioenergy industry.

1. Coordinate development of producer groups and biorefineries and establish efficient business structures

Formation of producer groups and biorefineries must be coordinated to ensure that a consistent supply of biomass is available to the biorefineries, particularly for perennial crops with longer establishment periods,[216] and that a regional buyer exists for feedstock production[217] to leverage regional production costs relative to other options.[218]

Concepts built on promoting bioenergy and invested memberships were noted by some of the participants. Producers should be able to invest check-off dollars towards research and development of bioenergy commodities and returns should be made to the investor in some form of benefit or credit, e.g., New Generation Co-ops.[219,220]

2. Modify agricultural input to maximize production

The appropriate use of agricultural inputs (i.e., nutrients, pesticides, herbicides) and land management practices are important factors in determining crop output response and maximizing production.

Sustainability, cost, and long-term environmental effects must be considered when developing a secure market for herbaceous energy crops.

To maximize profit, it is important to reduce input costs (i.e., nutrients, pesticides, and herbicides)[221] where possible. One way to reduce these costs is to use the waste generated during distillation, which has some nutrient value, as a fertilizer supplement that is returned to the production land.[222] The environmental implications of this need to be considered.[223] Development of other innovative landscape-scale management strategies may also reduce the need for certain inputs.[224]

Research on the optimum form of the plant is needed to determine the harvest index that maximizes the yield over time for energy production.[225,226] A major barrier to improving all of the crops discussed except switchgrass is the USDA's inability to deal with importation of germplasms for breeding at an adequate scale and speed.[227] However, increased yields from genetic technology could lead to greater market viability if crop longevity is not sacrificed.[228,229] Maintaining yields for a prolonged period of time (i.e., switchgrass stand life of 10 years) will be important to the sustainability of a crop.[230] Since perennial crops typically yield less in the first few years of production, financing of long-term energy projects will be very sensitive to early year input costs. Improving yields of perennial crops soon after establishment could be a key factor in improving economic viability.[231] Growth regulators also should be researched, (i.e., application of herbicides at low rates)[232] and innovative landscape-scale management strategies explored for their potential to increase yields.[233]

3. Develop regional crop management protocols

Reliable, inexpensive, and efficient crop establishment protocols (esp. small seed crops) will need to be developed by region, regardless of crop, to assist producers during start-up.[234,235] Co-cropping management strategies also need to be developed to support economic viability and environmental sustainability.[236] In addition, regionalized BMPs should also be developed and available through extension services to benefit producers throughout the lifetime of the crop.[237]

4. Crop versatility and diversification

Increasing the opportunities for multiple uses of bioenergy crops[238] will reduce risk through diversification and provide better economic stability. Continuing research in agricultural systems is needed to identify these potential applications and should be performed for all crops.[239,240] This will have potential impact on other industries, such as the livestock sector.[241] This could enable biotech companies to play a role in creating markets for valuable proteins[242] and other high-value products. Some crops, such as switchgrass and miscanthus, could be grown for dual uses[243] as early season grazing forages for livestock and wildlife.[244,245,246,247]

5. Financing of capital investment for producers

Producers will need to establish lines of credit[248] in order to acquire fixed assets (land, machinery, buildings). Suggested financing opportunities included credit from machine manufacturers[249] and the creation of a dedicated financing branch exclusive to the energy crop industry.[250] It was also proposed that biorefineries could provide a harvesting service to the producers to improve harvesting efficiency and distribute cost of harvesting equipment across the region.[251]

6. Incentives and financing for crop establishment

Sufficient incentives and financing should be made available to producers to economically justify the shift from traditional agricultural crops to the establishment and production of bioenergy crops. [252] One important mechanism to support this is to determine regionally sensitive fair product pricing that accounts for differing inputs and land lease values. [253,254] This will help give producers financial stability and access to credit, which is critical for establishing the feedstock crops.[255]

The limited yield of perennial-type crops in the first few years of production generates restricted income and high start-up risk. A partial solution to this problem is to develop cropping systems that produce a yield during the establishment years, such as intercropping a perennial energy crop with an annual or, in regions with extended growing seasons, following a summer annual with a perennial in the fall.[256] Crop insurance programs may also help.[257]

The effective implementation of the biomass crop assistance program (BCAP) will be paramount to the economic viability of the industry in the coming years. Its extension for a least one more term in the next Farm Bill is even more critical to economic viability. Extension through 2017–2018 would be a means of financing for the producers through the first few years of limited income.[258] The next Farm Bill will be a threshold opportunity to assure that growers interested in producing energy have a good safety net.[259]

Currently, BCAP is not sufficiently targeted as much of the money appears to be paying for activities that would have happened anyway and do not incentivize adoption of energy crops. Payments should be limited to crops that are more economically viable and reimbursement for establishment costs should be relative to the total cost incurred (a crop that costs $5000/acre is compensated more than one that costs $800/acre) .[260] Additional financing may be important for costly systems with long-term potential.[261]

Long-term off take contracts may also help producers manage the uncertainties inherent in trying new crops. These agreements will need to be supported by insurance mechanisms that protect both the producer and the biorefinery in the event of production shortfall.[262]

7. Improve interagency collaboration

Many of the goals between the DOE and local agencies (USDA farm service agency) are the same, and sharing of information could benefit all parties.[263]

8. Reduce the cost of feedstock transportation

For maximum supply system efficiency, herbaceous biomass transportation costs must be minimized. Feedstock format and bulk density were identified as two major factors impacting cost efficiencies of transportation.[264] An enabler to reducing the cost of transportation is densification of biomass at the farm or co-op level by means of mechanical pre-processing such as briquetting or pelletization systems.[265] Studies have been performed to develop systems that can handle this diversity of biomass, but these projects are capital intensive and require more funding for completion.[266]

9. Incentives for renewable fuels and power generation

Incentive programs for production and use of domestic ethanol are critical in reducing U.S. dependence on fossil fuels and the emission of greenhouse gases. Motivating action through government policies is one enabler recognized. In some states, legislation mandates that energy generators and providers must increase procurement from renewable energy resources over time.[267] A market-motivated solution is to create value for environmentally friendly and sustainable solutions.[268] The most recognized system is the cap and trade on carbon dioxide emissions. Value could be generated for bioenergy crop producers through carbon sequestration.[269] The perennial nature of most bioenergy crops lends itself well to storing carbon underground in rooting systems. The challenge comes in accessing value (carbon credits) under different agronomic management practices. The use of carbon credits in trade requires methods to be developed that can consistently measure the amount of carbon that is stored in organic matter. Once carbon credit value can be accessed, policy makers can make decisions regarding appropriate regulations to manage trade transactions.[270, 271]

Potential problems arise from determining who will receive these financial credits as landowners and producers can both make a claim.[272,273,274] It is most likely the producer who will make decisions and administer various practices, but landowners are ultimately responsible for all land management activities. Landowners may influence producers to use certain solutions if they are entitled to part of the financial gain.

2.4 Alternate HYS Assumption – Land Use

Land for dedicated herbaceous energy crops will come from existing cropland, pasturelands, and rangelands.

The alternate high-yield scenario assumption presented to workshop participants was that land for dedicated herbaceous energy crop production will come from existing cropland, pasturelands, and rangelands. Land-use change decisions are currently based on relative net financial returns, with little influence by other positive or negative impacts.

Until the biomass conversion industry becomes active, energy crops have little or no value, and until energy crops can have a positive financial return, no land base will be available. As markets develop for commodity-scale corn stover and other agricultural crop residues, it is foreseeable that nonproductive land will move into production. There are concerns that changes in world land use will negatively impact climate conditions and vice versa. There are also concerns that residue removal incentives could encourage unsustainable land management practices and negatively impact future production and the environment.

Limiting Factors and Assumption Enablers

Participants were asked for their opinions about land-use issues related to increased demand for biomass resources. The discussion was brief, but participants emphasized the following observations and concerns:

There will be competition for land regardless of whether or not the United States moves forward with commodity-scale energy crop production,[275] thus is would be helpful to develop a better understanding of the best uses for all kinds of lands, especially marginal lands. The term "marginal lands" describes a variety of land-types that are not currently under production for a variety of reasons, and it would be helpful to clarify which types of marginal lands are options for energy crop production. A paper by Mooney et al. on marginally classed lands reports that 50% are classed as marginal because of slope, drainage issues, etc. and some are in CRP.[276]

While they may be not useable for row-crop production, they may be candidates for alternative uses, including energy crop production. We need to identify and determine values for these alternative uses[277] and use land more effectively,[278] matching species to the environments they were adapted for in the first place.[279] Production systems need to be designed to optimize marginal lands, such as using corners in pivot-irrigated fields[280] and rehabilitating acres idled due to crop failure, drought, poor economics,[281] etc. In areas where cool season grasses grow, switchgrass or other species could be used. Some of these lands are currently in CRP and other mixed season grasses.[282]

Converting pasture to energy crop production introduces different productivity issues than food production because perennial grass crops do not follow soil fertility like food crops do. They are instead more sensitive to rain fall and other environmental conditions.[283] Pasture that is classed as marginal because of slope may be good for perennial grasses,[284] but because there is already competition for pastureland, we also will need to improve remaining pasture that is used for livestock.[285]

Land-use shifts to support HEC production will challenge land managers because row crop producers look at economics differently than pasture managers. Management traditions may be hard to change.[286,287] U.S. land-use policy can support this transition, but these policies (and our projections) need to avoid factoring in global indirect land-use.[288]

2.5 Alternate HYS Assumption – Other Technology/Policy Advances

Other technologies, research initiatives, and policies that will impact future herbaceous energy crop production are identified.

Concluding discussions allowed participants to present additional thoughts about other technologies, research initiatives, and policies that will impact future herbaceous energy crop availability. Participants were asked for any additional suggestions that had not been presented in earlier discussions sessions, such as technology advances that could enable abundant supply to all biomass markets, suggested federal research initiatives to outline and fund all near- and long-term feedstock production and supply R&D, and policy initiatives to make available the land required to provide an abundant supply of biomass.

Limiting Factors and Assumption Enablers

The discussion was brief, but participants mentioned a couple of points with regards to future research initiatives: underestimated energycane potential and the "solar cap" that limits all crop types depending on where they are grown.

In energycane development, the varieties being evaluated now are old hybrids and are not a good representation of the crop's potential yield. New varieties are showing significant increases, and a 200% yield increase is possible with work in genetics and implementation of the right management practices. [289]

HEC development in some zones will require less investment depending on energy crop suitability; for example, Zone 4 mixed perennials and switchgrasses are likely to require less development than mixed grasses, and these programs will look different because they require lower investment.[290] However, performance of new crop varieties will be capped by solar gain availability of the specific region, regardless of other improvements to expand a crop's potential production range.[291]

Workshop Participant Bios

Bill Belden

Bill Belden, Sr., Agriculture Specialist with Antares Group, Inc., is a 1974 graduate of Iowa State University, where he received a BS in farm operations. He manages Belden Family Farms LLC, a family-held farming corporation in west-central Iowa that specializes in corn and soybean production. He also serves as Operations Manager for Prairie Lands Bio-Products, Inc., the Iowa producer group who conducted the fuel supply development function of the Chariton Valley Biomass Project. Bill worked for the Iowa Farm Bureau Federation as a Regional Manager for 24 years before becoming technical expert for R&D work including the Chariton Valley Biomass Project, the Abengoa cellulose-to-ethanol processing project in Kansas (Antares Group, Inc.), and development of harvesting protocols for miscanthus and biomass grinding activities (Idaho National Laboratory). Bill is a member of the Council on Sustainable Biomass Production (CSBP), a multi-stakeholder group developing voluntary biomass-to-biofuel sustainability principles and standards for the production of feedstock for second generation biofuels.

John Blanton

John Blanton, Jr., currently serves as Research Programs Manager for the Samuel Roberts Noble Foundation in Ardmore, OK. A 1998 graduate from Purdue University's meat science and muscle biology doctoral program, he has research in the areas of beef cutability and palatability as well as retail display and shelf life. He has researched in the area of cryopreservation of samples for histological examination. A founder of the International Center for Food Industry Excellence and co-director of the Center for Excellence in Cryobiology, Dr. Blanton has served on the faculty of Texas Tech University and as a visiting professor at the University of Groningen in the Netherlands. He has been Research Director at

Supachill Technologies in the UK, the Project Leader for pharmaceutical development at Intervet, Inc., and Director of Research for KVS Service in Georgetown, DE.

David Bransby

Dr. David Bransby, Professor of Agronomy and Soils at Auburn University, received his Ph.D. in grassland science from the University of Natal in South Africa in 1984. Since that time, his research interests have focused on the physical and chemical characteristics of switchgrass (*Panicum virgatum L.*), an important potential source of biomass for energy production. His preeminence in the field is signaled by his service advising President George W. Bush, DOE Secretary Sam Bodman, and senior administration officials on cellulosic biofuels in 2007. A Fellow of the American Society of Agronomy, has taught at universities in the Republic of South Africa and in the United States.

Cory Christensen

Cory A. Christensen received his doctoral degree in Biology in 2001. Since that time, he has served as a senior associate and a research scientist at Icoria, Inc., and a trait manager, Switchgrass Product Manager and, finally, as Director of Product Management for Ceres, Inc., of Thousand Oaks, California. He has published articles and book-length treatments on Arabidopsis genetics, drought resistance, and switchgrass as a crop for biomass energy production. Dr. Christensen holds, with others, five patents in the area of gene sequencing and characterization. He is a member of the Western Seed Trade Association where he serves on the Environmental and Conservation Seed Committee.

Fred Circle

Fred D. Circle is president and CEO of FDC Enterprises (FDCE), a company whose mission is providing pesticide application services for an emerging customer segment: ultra environmentally sensitive niche markets. FDCE industrialized applications of specialty herbicides to greatly eliminate springtime mowing regiments for roadside maintenance departments. Management's philosophy is to focus on chemistry dosing to help protect the environment; because of this, FDCE was awarded QVM certification, global recognition of the world's top 48 herbicide application companies. FDCE's professionals have over 70 years' conservation experience. This experience combined with collaborative efforts with prestigious universities and academic foundations sets them apart from others in the industry. FDCE has leveraged its experience in site evaluation, superior input products, and production efficiencies to develop a turn-key service that results in predictable success on every project.

Ken Goddard

Ken Goddard has an M.S. in Animal Science from the University of Tennessee (UT) and is a UT Extension biofuels specialist. He currently works to establish switchgrass as a dedicated energy crop under Tennessee Valley Authority (TVA) power line easements, Oak Ridge National Laboratory (ORNL), and Community Reuse Organization of East Tennessee (CROET). Mr. Goddard serves on the Henry County Rural Development Committee, the Soybean Crushing Plant Feasibility Study Committee, the State Switchgrass Production Team, and the Switchgrass Production Committee, to name just of a few of his professional activities.

Neal Gutterson

Neal Gutterson has been CEO of Mendel Biotechnology since February, 2007. He joined Mendel in June 2002 and served as vice president (VP) of research and development (R&D) then chief operating officer, prior to his appointment as president & COO in December 2005. Neal is a member of the Board of Directors. He has been involved in plant biotechnology since 1983, when he joined the fledgling biotechnology company AGS, to develop genetically improved microbial biocontrol agents. Before joining Mendel, he spent 18 years at DNA Plant Technology Corporation (DNAP), where he managed diverse research programs and corporate relationships and then served as VP of R&D for several years. He is a named inventor on more than 2 dozen patents and pending applications. Dr. Gutterson holds a

Ph.D. in Biochemistry from the University of California, Berkeley, and a B.S. in Chemistry from Yale University. He also attended the Stanford Graduate School of Business for an executive education program. He serves as a member of the Food and Agriculture Section and the Industrial and Environmental Section Governing Boards of the Biotechnology Industry Organization. He also serves on the executive committee of SCRA, a program to support regulatory approval of biotech specialty crop products, and on the steering committee of CSBP, the Council for Sustainable Biomass Production.

Stephen Long

Stephen Patrick Long is deputy director of the University of California–Berkeley (UCB)/University of Illinois at Urbana–Champaign (UIUC) BP Energy Biosciences Institute. Concurrently, Dr. Long is an Edward William and Jane Marr Gutgsell endowed professor for the UIUC Departments of Crop Sciences and of Plant Biology and a faculty fellow at the National Center for Supercomputer Applications. Prior to this, he was a full professor for the Department of Biological Sciences at the University of Essex in the United Kingdom (U.K.) as well as director of Photosynthesis Research and director of Biology Undergraduate Schemes. Because of his vast expertise and numerous publications, Dr. Long is listed among the 250 “Most Highly Cited” authors of Animal and Plant Biology by the authors of Science Citation Index (http://isihighlycited.com/) and “Top 20 Authors Overall” on the topic of Global Warming (www.esi-topics.com/index). He holds a D. Sc. in Environmental Sciences from the University of Lancaster, a Ph.D. in Environmental Physiology from the University of Leeds, and a B.S. in Agricultural Botany from the University of Reading, all in the U.K.

Tom Lutgen

Tom Lutgen started with the family-owned Star Seed company in 1976 and became president in 1984. Star Seed has been a member of the American Seed Trade Association (ASTA) since 1948 and a member of the Kansas Seed Industry Association since its inception in 1950. Mr. Lutgen is past president of the Kansas Seed Industry Association, Field Seed Institute of North America and the Western Seed Association. Tom has also served on the boards of the Kansas Crop Improvement Association, AgVantage IP, and the board of the American Seed Trade Association as a regional vice president. He has served on many committees of the ASTA including serving as chairman of the Farm Seed Division of ASTA.

Vance Owens

Vance Owens holds a Ph.D. in Agronomy from the University of Wisconsin. He presently works as a professor at South Dakota State University, where he was previously an associate professor and an assistant professor. Dr. Owens has co-authored numerous publications, the latest of which include “Morphology and Biomass Production of Prairie Cordgrass on Marginal Lands” and “Biomass and Seed Yields of Big Bluestem, Switchgrass, and Intermediate Wheatgrass in Response to Manure and Harvest Timing at Two Topographic Positions,” both published in 2009 in *GCB Bioenergy.* He is a member of the American Society of Agronomy, the Crop Science Society of America, the Soil Science Society of America, the Midwest Forage Association, and the American Forage and Grassland Council. Dr. Owens has presented several invited presentations regarding biomass production at national and international meetings.

Edward P. Richard, Jr.

Ed Richard is a supervisory research agronomist, research leader, and location coordinator for the United States Department of Agriculture’s Agricultural Research Service (USDA ARS) Sugarcane Research Laboratory in Houma, Louisiana, a job he has held since 1980. The focus of the Lab’s research is to provide research-based solutions that enhance the viability of sugarcane as a sugar and/or biofuels feedstock. Dr. Richard has been instrumental in the release of three high fiber sugar cane varieties to the biofuels industry and the expansion of laboratory’s research efforts to develop cold-tolerant varieties of sugar cane that can be successfully grown as bioenergy feedstocks in areas outside the traditional cane-growing areas of the U.S. In addition to serving on a number of parish, state, and international sugarcane-related advisory committees, Dr. Richard has received several national awards including the ARS Technology Transfer Award in 2006 for Superior Effort in the Development and Transfer of Improved Sugarcane Varieties to the Louisiana Sugarcane Industry and in 2008 as one of ARS's Senior Research Scientists.

William Rooney

"Bill" Rooney is a professor in the Department of Soil and Crop Sciences at Texas A&M University (TAMU), where he has been employed since 1995. His focus areas include sorghum breeding and genetics including germplasm development, breeding methodology studies, and genetic inheritance of agronomically important traits in sorghum (grain, forage and bioenergy). Dr. Rooney also teaches graduate plant breeding courses and is a graduate research advisor in plant breeding. Thus far, he has authored 69 journal articles and six book chapters and has participated in 34 invited presentations. Synergistic activities include acting as chair for the Agrilife Plant Release Committee, which provides merit-based reviews of proposed plant releases by Agrilife plant breeders/scientists.

Workshop Notes and References

1. There were three high fiber sugarcane varieties released from Louisiana, L 79-1002, HoCP, 92-550, and Ho 00-961. Citations are as follows:

   Bischoff KP, KA Gravois, TE Reagan, JW Hoy, CA Kimbeng, CM LaBorde, and GL Hawkins (2008) Registration of 'L 79-1002' Sugarcane. J. Plant Regist. 2: 211-217.

   Tew TL, EO Dufrene, RM Cobill, DD Garrison, WH White, MP Grisham, Y-B Pan, BL Legendre, EP Richard Jr, and JD Miller. Registration of 'HoCP 91-552' Sugarcane. J Plant Regist (In Press).

   White WH, TL Tew, RM Cobill, DM Burner, MP Grisham, EO Dufrene, Y-B Pan, EP Richard Jr, and BL Legendre. Registration of 'Ho 00-961' Sugarcane. J. Plant Regist. (In Press)

   Of the three, L 79-1002 is the more customary high fiber/low sugar type of energy cane with a yield average of 10 ton/acre. At the upper end of the yield estimate is Ho 02-113. It was released in 2010, but the manuscript has not been prepared yet.

2. McIsaac GF, MB David, CA Mitchell (2010) Miscanthus and switchgrass production in central Illinois: Impacts on hydrology and inorganic nitrogen leaching. J Environ Qual, 39:1790–1799.
3. Research on mixed perennial grasses not comprehensive...switchgrass has been focus.
4. Long history of work in the US with switchgrass, causes resistance to emerging and much higher yielding alternatives - energy cane, elephant grass and Miscanthus.
5. Lack of background research into the agronomy, breeding systems, and environmental sustainability of these crops, relative to our major feed/food crops.
6. Slow pace of genetic improvement.
7. Major need for accelerated government funding for understanding of the genomes of these crops to support accelerated.
8. Efficient use of nutrient amendments.
9. Predictability of plant emergence.
10. Yield effects of herbicide practices- post plant.
11. Disease and insect control.
12. Water use efficiency.
13. Geographical adaptation of these crops.
14. Yield model should pick the best crop solution or set of solutions within a cropping system for a given geography.
15. Intercropping with N-fixing legumes is a more practical approach than engineering plants to accomplish this.
16. Plant produces its own N.
17. Insufficient water for viable yields of all of these crops without irrigation in most of the west.
18. With irrigation or without irrigation there is no in-between…. Certain crops won't grow without irrigation.
19. Sustainability of energy to grow an energy crop.
20. Energy crops will only be produced in regions with adequate water supplies. Other energy sources will be deployed in western regions, for example.
21. In the western and central states, the payment for switchgrass will need to exceed the value of other irrigated crops such as cotton or wheat.
22. What would producer need to get financially to make irrigated switchgrass viable?
23. Look at the work of Dan Putnam at UC Davis and Steve Fransen and Washington State on irrigated swg.

24. Producer management skills and techniques.
25. Production risk tolerance.
26. Crop insurance is a possible mitigation.
27. Lack of existing markets for all bioenergy crops.
28. Inadequate government support programs (BCAP has several weaknesses).
29. Financial support to build the infrastructure to deliver the supply.
30. Limited breeding for improvement in many current varieties.
31. Breeding cycle long for perennial crops 10 years = 25 to 30% increase. Plenty of opportunity to increase yields. Short run = 2 tons per acre. Long run = double yields. Breeding would increase germination, imp varieties, imp insects/disease resistance.
32. Limited number of Breeders in US.
33. There are significant and comprehensive breeding programs being run by private industry and universities.
34. Establishment challenges.
35. Large seeds are by far the preferred propagule.
36. Germination rates not optimized.
37. More difficult to handle in mechanized planters; dormancy; limited energy stores; seedling vigor; seeding rate.
38. Weed management during establishment. (need labeled herbicides)
39. Predictability of plant emergence needs to be improved.
40. Seeding depth, rate.
41. Limited weed control options during establishment. Weed control
42. Timing, weed control and no till practices.
43. Timing, weed control and no till practices.
44. Relative to what? Baseline data needed.
45. Will high concentrations of acres dedicated to one species increase probability of crop pests, diseases and insects?
46. Producer knowledge of establishment/production/management practices for SG and MG.
47. Extension Service would play valuable role.
48. Costs per ton may increase with yield increases (added fertilizer, equipment wear and tear, increased labor). Fertilizer increases are proportionate to yield increases. Moving switchgrass from field to farm gate is expensive. Equipment improvements are needed. Need more efficient ways to harvest. Staging and storage of energy crops is costly and time consuming. (Covers, all weather roads for large transport trailers, distance to markets, distance to storage areas, etc.)
49. Market availability and costs of production.
50. Competition for land resources for alternative crops.
51. Low economic return in establishment years
52. Cost analysis. Add return to risk and management in budgets. Lodging problems increase with yield increases. Costs per ton may increase with yield increases (added fertilizer, equipment wear and tear, increased labor). Fertilizer increases are proportionate to yield increases. Moving switchgrass from field to farm gate is expensive. Equipment improvements are needed. Need more efficient ways to harvest. Staging and storage of energy crops is costly and time consuming (covers, all weather roads for large transport

trailers, distance to markets, distance to storage areas, etc). In many cases land has been idle for a reason. Idle land planted to switchgrass must have land preparation costs included.

53. Lack of genomic information to support advanced breeding.
54. Major opportunity where government support can spur development of a viable bioenergy industry.
55. Breeding cycle long for perennial crops.
56. Government support for marker assisted breeding systems, and identification of genes for key yield traits, could make a major impact on yield.
57. Lack of well-characterized germplasm from range of relevant species.
58. Current information on narrowly adapted single genotype, need info for more broadly adapted germplasm.
59. Companies may be in best position to secure germplasm resources and deploy for finished varieties.
60. High cost of establishment for vegetative propagules.
61. Clonal propagation systems challenging for rapid varietal improvement cycles.
62. Established protocols have been developed in the EU, where several thousand acres are now planted.
63. Lack of a seed production system.
64. Significant advances now in development of seeded Miscanthus spp.
65. Lacks established weed control systems. Weed control is critical during establishment, but not needed in established stands.
66. Very low yields.
67. Can grow mixed grasses on marginal land.
68. These can be grown on somewhat to quite marginal land; perhaps more a barrier in sorghum.
69. Use on marginal land is actually an advantage.
70. Mixed grasses minimize establishment risk when different variables could be limited.
71. Breeding cycle long for perennial crops.
72. Difficulty working with mixtures.
73. Different seed sizes and types make it difficult to plant uniformly.
74. Costs are a function of supply and demand.
75. Seed availability and cost is a barrier. Some species are very expensive others are very reasonably priced.
76. Establishment challenges. (e.g., herbicides, seed cost, etc.)
77. Predictability of plant emergence not optimized.
78. Producer knowledge of establishment/production/management practices.
79. Breeding cycle long for perennial crops.
80. Need to collect wild species and related genera for trait introgression by breeders.
81. Collections to foreign countries where wild species of sugarcane and related genera such as Miscanthus and erianthus should be sponsored.
82. Need to expand breeding program.
83. Sustainable agronomic practices not determined outside of traditional cane growing areas.
84. Nutrient requirements will differ depending on soil and environment.
85. Nutrient requirements will differ depending on soil and environment.

86. Lack of knowledge as to handling sugar.
87. Lack of developed technology to process water, sugar, and fiber components for biofuels production.
88. Need to educate growers as to how to grow and plant perennial row crop.
89. Experience is lacking and they are reluctant to plant a crop which requires a long term commitment if cropland is to be used.
90. Resistance (in some cases, unjustified) from environmental advocacy organizations.
91. Biotic and abiotic stress tolerance.
92. Nutrient-use efficiency.
93. All these crops are C4 species and use water physiologically at the same rate.
94. As an annual nutrients will not be recycled as they will for fall harvested perennials.
95. As an annual crop, higher nitrogen input requirement.
96. Addition of legumes to a bioenergy feedstock production system that will reduce nitrogen requirements and maintain yields.
97. Yield Trials on the actual land area that the crop will be intended to as well as university trials.
98. Trials should be conducted on the actual land area that the crops are intended to be planted.
99. Yield trials on regional basis.
100. Use best-in-class varieties.
101. Move away from small plot work, to producer managed trials.
102. Larger trial vs. small plot scale.
103. Side by side trials of monocultures and mixtures by region.
104. Need to do this also across different land capability classes.
105. Analyzing the best crops per region.
106. Need to discover how far north and west viable yields of Miscanthus may be achieved.
107. Establish how far north Energy cane, Miscane and Elephant grass (Pennisetum purpureum).
108. Competitive yield trials.
109. Optimal mix by region and also use as conservation/ wildlife crop or dedicated energy crop.
110. Optimal mix of crop types by region.
111. Side by side trials of monocultures and mixtures by region.
112. Improve energy yield per ton via improved genetic traits.
113. The need for larger sampling (plots vs. field level research). Lack of knowledge of how land variability, weather, production capabilities of the land.
114. Best Management Practices to be deployed by crop per region.
115. Better understanding of the use of feedstocks and their end uses to optimize extractable energy per acre.
116. Side-by-side trials of the major crops are critical to addressing this.
117. Need to have regionalized establishment practices prior to making cost comparisons. Establishment in one region does not transfer to other regions.
118. These need to be done using commercial technologies to harvest not hand harvesting under ideal conditions.

119. Need to consider full cost from seed production through harvest, some crops look great but do not fit into a commercial seed industry
120. Biorefineries will need to be involved in the decision process, in that bioreactors efficiencies are effected by feedstock composition
121. Good opportunity for collaboration with national labs, academics and companies
122. A R&D ecosystem should be fostered by the government, much like that for major crops, in which academic labs and government agencies develop genetic resources, and collaborate with companies that produce finished varieties
123. An important opportunity is heterosis, where major acceleration in rates of yield improvement can be derived. This should be developed further in SG, M, perhaps E.
124. Site and timing specific nutrient amendment- yield effects of feeder crops(legume N fixing)
125. Seed enhancements… including seed treatments, coatings… Seed enhancements are common in all other crops.
126. Seed enhancements, seed size, seedling vigor, herbicide tolerance
127. Vegetative Propagation for establishment issues
128. Nitrogen fixation of perennial grass.
129. Development of herbicide resistant feedstocks
130. For all crops and regions - is glyphosate tolerance possible
131. Weed control during establishment period is #1 problem. We need more research in chemical weed control
132. Weed control during establishment period is #1 problem. We need more research in chemical weed control
133. Best done by University extension, involve Ag Chemical Co's in understanding developing market
134. Weediness of feedstock needs to be established if biofeedstocks are to be integrated into adjacent food crop acres
135. Impact weed contamination in any harvested crop (feedstock) has on biomass production for fuel
136. What about diseases and insects as acreage increases
137. Major opportunities to deploy traits developed for major row crops in these energy crops
138. Known genomes could be leveraged in comparative genome approaches.
139. Improved regulation of flowering to assure maximization of biomass with limited seed production in production fields. Leverage known genomes in comparative genome approaches
140. Biotech traits to expand a species to dryer areas
141. Stress tolerance genes would help all crops as we address sustainability issues
142. Transformation systems must be combined with improvement programs to provide an outlet for the technology in improved varieties
143. Molecular traits would help and probably would come from commercial sector
144. Lodging problems increase with yield increases.
145. Miscanthus has been shown to yield without any added N for many years, suggesting N-fixation. Understanding the endophytes involved and the plant-symbint interaction could lead to improving other grass crops.
146. This might also include legumes in with grasses.
147. Adoption of no-till agriculture.

148. Applies primarily to annual species but could also involve seeding year in perennials

149. Emerging concepts in soil and crop management practices, tillage, rotational strategies, integrated cropping systems; cover crops, manure management, weed and disease management (Genetics? Chemicals?), energy efficiency

150. These all impact soil erosion.

151. Develop planned production programs and systems (switchgrass). Improved control of grassy weeds during establishment would allow for starter fertilizer applications and increased yields in year one. Establish recommended production BMP's (Best Management Practices) by regions.

152. Studies to identify yield-limiting factors across geographies.

153. Weed/herbicide management.

154. Minimize nitrogen use.

155. Define how much nitrogen might be needed to initiate an effective, perennial energy crop plantation, and understand full energy impact over lifetime of that plantation.

156. Incorporation of legumes and its effects of yield (SG).

157. Intercropping with legumes to reduce N input requirements.

158. Nitrogen fixation of perennial grasses.

159. N fixing microorganisms.

160. Filter strips.

161. Minimizing N in the Mississippi basin.

162. Develop strategy to minimize risk of new biomass crops coming invasive (all species).

163. Assuring that new varieties of perennial energy crops have a low potential for invasive where introduced.

164. Need to make sure this does not employ the precautionary principle and is based on real-world experience with these crops not just models. While a Chevy and a Ferrari both have 4 wheels and an engine, their performance is quite different.

165. Prevent inter-crossing of improved switchgrass and other prairie grasses with native prairie.

166. Not likely for anything other than improved swg intermating with wild swg. No expectation of cross compatibility with other species.

167. Genetic technologies to prevent intercrossing with weedy relatives and transgene escape.

168. Both conventional strategies for biomass crops to reduce seed production as well as biotech strategies.

169. Use of male sterility system to reduce/avoid gene flow.

170. Use of delayed flowering to eliminate the reproductive phase of growth.

171. This emphasizes the importance of this trait, as this supports both yield improvement and supports sustainability through non-invasiveness of plants/genes.

172. This could be addressed by controlling flowering; e.g., exploiting variation in day length requirements in germplasm.

173. Develop exit strategies for species development to address invasive issues.

174. Improved carbon sequestration through root and rhizome development.

175. Growers in the future will be able to produce both above-ground carbon for energy, but also to "farm" below-ground carbon, and receive income for that, as a direct step to reduce atmospheric CO2 (carbon negative cropping).

176. Measures of actual root and rhizome biomass would help document this process.

177. Methods of monitoring, indirectly, carbon accumulation in the soil.

178. Studies of prairie grass Prairie vs. Dedicated Energy Crops (mix Big Bluestem-Indiangrass-Switchgrass).

179. To include selecting lines that produce refractile litter.

180. Develop planned production programs (SG).

181. Include Mixed Grass.

182. Include all crops.

183. Development of a fallowing system effects on establishment and environment.

184. Yields are increased following wheat for hay or balage, following ryegrass for hay, or following previous row crops due to reduced weed competition. Better stands, quicker germination, reduced weeds are the result of these planting systems.

185. Tall Fescue and other weed grasses can best be controlled in the fall allowing for increased use of no-till.

186. Studies to identify yield-limiting factors across geographies.

187. Landscape planning to address soil erosion issues.

188. Matching species to soil and landscape.

189. Desirable to have more than one viable bioenergy crop for each region.

190. Addition of legumes and its effect on forage mass (SG).

191. Dual use opportunities and their effects on environment.

192. Ways to manage changes in land use for energy crop production with minimal loss of soil carbon.

193. Improved sustainable practice, for example, through herbicide treatment of pasture prior to conversion to a high-yielding energy crop rather than tilling that pasture prior to conversion. Animal residue removal as a potential part of pasture transformation prior to herbicide.

194. Provide financial incentive for indirect goods and services.

195. Need studies to quantify benefits of environmental services (value to producer).

196. With needs for improved sustainability, we need ways to compensate farmers for their efforts. This could come from programs such as "payment for ecosystem services", along lines done by NRCS in some cases.

197. Consider CRP-type payments for conservation practices that allow harvest of biomass.

198. Educate NRCS and other government agency…. Team approach. DOE & USDA BLM others. Should be collaborative effort not independent initiatives.

199. Perennial crops to increase soil carbon.

200. Maximize the nutrient recycling capability of herbaceous perennial grasses.

201. Nutrient remobilization late year a key attribute, requiring single-pass, late season harvest, to maximize value of perenniality.

202. Minimizing soil erosion, esp. of sloped land.

203. Assume leaving residue on helps but can hinder next year's crop.

204. IPM program development for SG-MG.

205. Full systems development for all perennial crops and cropping system.

206. Applies to all crops.

207. Insect management will also be issue both within the feedstock and on adjacent crops.

208. Pest management include diseases.

209. RR corn and BT corn have been shown to reduce use of chemicals and benefit the environment in terms of beneficial insect species.
210. Also supplemental irrigation or deficit irrigation strategies to optimize biomass yield on reduced water input.
211. When to harvest is important especially when commercialized and growers are asked to harvest early.
212. Should time of harvest be dictated by crop age - doubtful that a 7-year old stand of swg will yield as much as a 4-year-old stand under commercial production.
213. Will annual harvest diminish stands of switchgrass and or mixed stands.
214. Harvest strategy effects on SG. One or two harvest? Harvest after frost? Physiological maturity?
215. Important to determine how much residue should stay on soil for erosion and nutrient recycling.
216. Especially important for perennial crops with longer establishment periods.
217. Regional buyers for feedstocks.
218. Regional production costs relative to other options.
219. Check-off dollars for producer groups.
220. New Generation Cooperatives (example).
221. Reduced inputs (i.e., nutrients, pesticides, herbicides).
222. Waste generated during distillation has some nutrient value that can be returned to the grower as a fertilizer supplement. Environmental implications need to be considered.
223. Waste generated during distillation has some nutrient value that can be returned to the grower as a fertilizer supplement. Environmental implications need to be considered.
224. Reduced inputs and higher yields due to landscape-scale management strategies.
225. Improve the harvest index.
226. Research on the optimum form of the plant to maximize the yield.
227. A major barrier to improving all of these crops, bar switchgrass, is the USDA's inability to deal with importation of germplasms for breeding at an adequate scale and speed.
228. Increased yields.
229. Without sacrificing longevity.
230. Maintaining yields for a prolonged period of time (e.g., SWG stand life of 10 yrs) will be important.
231. Financing of long-term energy projects will be very sensitive to early year sunk costs, so increased yields soon after establishment is key.
232. Growth regulators should be researched these could be herbicides at low rates.
233. Reduced inputs and higher yields due to landscape-scale management strategies.
234. Reliable, inexpensive, and efficient crop establishment protocols (esp. small seed crops).
235. These will differ for various regions regardless of crop.
236. Co-cropping management strategies.
237. Develop regionalized BMPs that can be delivered through extension service.
238. Multiple products.
239. Research in Ag systems.
240. Applicable to all crops.
241. Impacts on livestock sector (and other industries).

242. This is very important and where biotech companies could play a role e.g., valuable proteins.

243. Increase opportunities for dual uses of bioenergy crops.

244. Dual use for grazing.

245. Dual use of SG - use for early season grazing.

246. Grazing early season forages.

247. Anytime SG is used MG should be included in comments.

248. Financing opportunities for producers.

249. e.g., Farm credit from John Deere.

250. Financing arm exclusive to energy crops.

251. Biorefiners could provide harvesting of fields to improve harvesting efficiency as well as spread out cost of harvesting equipment.

252. Incentives during establishment years…. Financing for establishment costs. {facilitator}

253. Fair price for product.

254. Determine appropriate land lease values by county.

255. Determine average break even prices for producers by region that account for differing inputs. This information will be critical for getting producers to establish the feedstock crops.

256. Yes, BCAP or studies on cropping systems that give yield during establishment year (e.g., intercropping a perennial E crop with an annual so that the annual gives yield in the first year or planting summer annual followed by SG in a fall planting [only works in the south])

257. Crop insurance programs.

258. The effective implementation of BCAP is key to economic viability of the industry in the next years. Its extension for at least one more term in the next Farm bill is even more critical to economic viability. Extension through 2017-18 as means of financing for first 2-years period of little/no-income.

259. The next Farm Bill will be a threshold opportunity to assure that growers interesting in producing energy have a good safety net.

260. BCAP program not sufficiently targeted. Much of money appears to be paying for activities that would have happened anyway and not incentivizing adoption of Ecrops. Should also be limited to crops that are closer to economically viable. Reimbursement for establishment costs should not treat a crop that costs $800/acre the same as one that costs $5,000/acre.

261. But need to finance more costly system may be important for systems with long-term potential.

262. A related issue is the need for insurance mechanisms to support the long-term contract: who pays if there is a production short-fall, and inadequate amount of feedstock is available for power or Biorefinery Company?

263. Improved interagency collaboration.

264. Increase density of harvested bales.

265. Develop briquetting or pelletization systems at the farm or co-op level.

266. Studies have been done by private industry. Capitalization to finish projects is limiting factor.

267. Require generators and fuel producers to provide a mandated and increasing proportion of renewable energy.

268. Value of other indirect goods and services (e.g., wildlife, C seq., etc.).

269. System for soil carbon sequestration monitoring and financial credit.

270. Implement a value for the carbon content.

271. Regulations to deal with the transactions.

272. Landowner vs. producer payback.

273. Have value transferred to producer or landowner.

274. Landowner vs. producer issues.

275. This is going to change whether we grow energy crops or not - there is going to be competition for land no matter what.

276. What is meant by marginal lands - what are yield expectations on other types of land - paper by Mooney et al. on land class shows 50% of lands sloping, moderately drained, etc. Some were CRP.

277. We need to determine values for alternative uses of land.

278. We need to identify and better utilize lands.

279. We need to match species to the environments they were adapted for in the first place.

280. We can use corners of center pivot-irrigated lands.

281. Environmental crisis % of acres that are failed, and doesn't get an economic yield from that land every year.

282. Certain areas of the country have cool season grasses where switchgrass or other species could be used. Some of them are CRP and other mixed season grasses.

283. Perennial grass crops do not follow soil fertility like food crops do. Perennial grass crops tend to follow rain fall, etc.

284. Often pasture is classed that way because it is on a slope, but it may be good for perennial grasses.

285. Pastureland is competed for, so we need to improve remaining pasture that is used for livestock.

286. Row croppers will look at economics differently than pasture managers - land use shifts will be a big challenge, a psychological issue.

287. Age is big issue in pasture crop vs. row crop, too.

288. Avoid putting global indirect land-use projections into US policy - that will kill things here.

289. On energycane, old varieties are being evaluated now - we have new varieties that are coming out and I think we can come close to 200% yield increase - in addition to genetics, these also incorporate agronomic practice improvements.

290. Zone 4 mixed perennials and switchgrasses are likely to have less development than mixed grasses - they should look different because they require lower investment. Zone 4 will also receive less investment than other regions.

291. Maximum value is capped by solar, so Maine will get 50% of other more well-lit regions.

WORKSHOP 3 – WOODY ENERGY CROPS

Workshop Participants[a]: Bill Berguson, Starling Childs, Mike Cunningham, Michele Curtis, Howard Duzan, Thomas Fox, Rob Harrison, Alan A. Lucier, Mike Schmidt, James Rakestraw, Robert Rummer, Tim Tschaplinski, Tim Volk, Ronald S. Zalesny, Jr.

Defining the Resource and Establishing Baselines

"Woody Energy Crops" (WEC)

Woody energy crops (WECs) are usually referred to as purpose-grown plantations in which the bolewood, probably the bark, and much of the limbs and tops are used as feedstocks for energy. They can also be referred to as short-rotation woody crops (SRWCs). Currently, SRWCs are grown primarily to use the bolewood for pulpwood and, in some limited cases, for lumber. In the general sense, energy crops and SRWC are intensively managed, fast-growing species that produce large amounts of wood and woody biomass over a short period of time, usually less than 10 years. Depending on the species and the production method, the rotation length can be shortened for purpose-grown energy crops to as little as 2 years when coppiced (clumped trees resprouted from stumps), but rotations are typically 5 to 12 years when grown as single trees from cuttings or seedlings. Several harvests are generally made from the coppiced plantation before being replanted, and after three to seven harvest cycles, the stumps are removed or killed and replaced with new, improved-quality stock. Usually after one harvest from the single-tree plantations, they are replanted with improved planting stock.

Efforts to develop SRWCs for energy began in the 1970s. When the wood markets for energy failed to materialize in the 1980s, efforts for single-tree SRWCs switched from growing energy wood to fiber or multiple products in the 1990s. More effort has gone into growing high quality trees for pulpwood and

a. Workshop participants provided the content of the report through survey answers and in-workshop comments. Individual participants are responsible for only the opinions and data they provided. Workshop report editors are responsible for assimilation of workshop data and participant comments in this summary.

other higher-valued products and less effort has gone into maximizing total biomass yields during this time. As the focus has turned back to energy, WECs are further developed with different rotation lengths and a mixture of plantings and coppicing in the same plantation to maximize production and reduce costs over various harvest cycles.

The U.S. Census of Agriculture defines SRWCs[b] as woody crops that grow from seed to a mature tree in 10 years or less and are used by the paper or pulp industry or as engineered wood, but not lumber. Although the general consensus is that SRWCs are 10-year rotations or shorter, and that woody energy crops are even less, only a few states have defined SRWCs to be woody crops grown in rotations of less than 10 years. They have done this to give them an agricultural classification. For many, the definition is arbitrary, more concerned with capitalizing on maximum mean growth increments for optimal economic returns. The Census reported 228,335 acres of SRWCs in 2007. Again, it is believed that few of these are energy plantations. They are mostly fiber plantations or specialty uses such as windbreaks and protection strips.

It needs to be pointed out that not all forest plantations are SRWCs. These plantations have rotations longer than 10 years, but less than the rotation of their natural counterparts. This is because there is usually intensive management involved such as site preparation, improved planting stock, fertilization, and competition control. There are many levels of intensity depending on site conditions, goals, and market demands. These plantations can also be a source for energy feedstocks, but most likely as only the biomass component of the stand. The remaining merchantable wood is expected to go to higher-value uses.

Currently, about 13%,[c] or about 64 million acres, of the timberlands in the United States are artificially regenerated, i.e., loosely defining them as “plantations” because of their even-aged stand structure. In the South, there are about 38 million acres of pine plantations with rotations between 20 and 35 years. New science and technology are reducing these rotations to even less.

Potential Woody Energy Crops

All of the major, potential woody energy crops have had significant research investment in improving yield from genetic breeding and/or biotechnology, nutrition management, and competition control. For example, in the September 2006 issue of *Science*, it was announced that the Western Balsam Poplar (*P. trichocarpa*) was the first tree to have its full DNA code sequenced[d]. There is also an effort ongoing to map the genome of the loblolly pine.

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b. USDA, 2009. 2007 Census of Agriculture – United States Summary and States Data, Volume, Geographic Area Series, Part 51. USDA, National Agricultural Statistics Service. Servicehttp://www.agcensus.usda.gov/Publications/2007/Full_Report/Volume_1,_Chapter_2_US_State_Level/st99_2_037_038.pdf

c. U.S. Forest Service Forest Inventory and Analysis. http://fiatools.fs.fed.us/Evalidator401/tmattribute.jsp.

d. http://www.phytozome.net/poplar.php.

In the 1980–90s, the U.S. DOE's Bioenergy Feedstock Development Program (BFDP) supported much development for hybrid poplar genetics and tree breeding. Since then, a national consortium that involves government researchers from several agencies, universities, and the private sector has conducted the task of improving hybrid poplar. Several forest industry companies made significant investments in the improvement of yield and the management of poplar plantations as well. Commercial plantings have been established in the Pacific Northwest, the Midwest, the Lake States, and the southeastern U.S.

In general, research has focused on reducing woody crop costs by improving yields, increasing pest and disease resistance, and developing efficient management systems. Although much of the focus was on yield and tree improvement through breeding and genetics, significant efforts have also gone into managing the soil and the competition from other species. Figure 3-1 shows yield increases from intensive management practices from pine plantations from the science developed over the past 50 years. Similar efforts, although probably not as long of a time, have been undertaken for the other species.

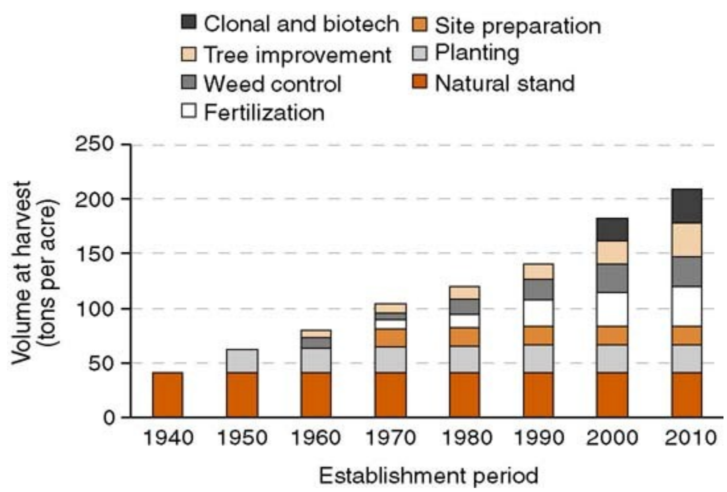

Figure 3-1. Estimated contributions of intensive management practices to productivity in pine plantations in the Southern United States from 1940 to 2010 (T. Fox , www.forest encyclopedia.net)

The most likely woody energy crop species to be developed for bioenergy production are *Pinus*, and *Populus*, *Salix* (willow), and *Eucalyptus* hybrids, but there are many other possible species, e.g., sycamore (*Plantanus occidentalis*) and sweetgum (*Liquidambar styraciflua*). This workshop focused on poplar, willow, and southern pine. Eucalyptus was added during the workshop discussions.

Poplar

Populus spp. is native to most of the Northern Hemisphere and includes 25–35 species. It includes poplar, aspen, and cottonwoods. For energy crops, we usually refer to the use of hybrid poplars, crosses between cottonwoods, as these are the ones genetically improved through breeding for enhanced production. Poplars are usually planted from cuttings and typically are replanted again after harvest in a pulpwood rotation to take advantage of those genetic improvements. However, poplar can grow from coppice and there is more interest in combining plantings and coppicing to maximize yields and reduce costs for energy.

Figure 3-2. Poplars grow fairly well in the northern, central, and southern United States. Extensive genomic resources, ease of clonal propagation and transformation, will allow the generation of advanced transgenic clones with enhanced traits. (Photo courtesy of Ron Zalesny, USDA-FS)

They can grow on many sites including infertile sands, but do best on moist, well-drained sandy and silt loams. They are expected to be grown on agricultural cropland and have a wide range depending on the species and the water availability. Poplars grow fairly well in the north, central, and southern U.S. In the west, they either are grown as cottonwoods along streams and bottomlands, or as irrigated crops of hybrid poplars; to date they have been limited to Washington/Oregon for production plantation. They do require management that includes proper site preparation, minimal fertilization, and weed/insect control. Harvest utilizes standard forestry equipment widely available in the United States.

Yield have ranged from about 3.5 to 6.0 dry tons per acre per year and are vary depending on site, climatic, genetic, and management practices. However, it is expected with continued improvements in planting stock and going to more intensive biomass management, that yields could be significantly improved, if not doubled in many regions.

Willow

Shrub willows (*Salix spp*) have had success as a perennial energy crop for the production of biomass for energy in Europe and more lately in northeastern U.S. The species used in woody crop systems are primarily from the subgenus *Caprisalix* (*Vetrix*), which has over 125 species worldwide[e]. Willows have several characteristics that make them an ideal feedstock for energy feedstocks: (1) high yields in 3–4 year rotations (2) ease of propagation of cuttings (3) a broad genetic base and ease of breeding (4) excellent coppicing ability, and (5) high energy content. They are usually grown at higher stand densities than other woody crops and cut to coppice several times before replanting. Willow grows best in moist soils in cold areas, but can be grown successfully on marginal agricultural land across the northeast, Midwest and parts of the southeast.

Figure 3-3. Shrub willows have several characteristics that make them an attractive energy feedstock: (1) high yield on 3–4-year rotations, (2) ease of propagation from cuttings, (3) broad genetic base, (4) excellent coppicing ability, and (5) the same energy content as other woody species. Willow grows best in well-drained to poorly drained soils in the northeast, Midwest, and mid-Atlantic regions.(Photo courtesy of CNH America, LLC)

They are grown from cutting and usually require cutting after one year to enhance yield from coppicing. The management is like the other woody crops requiring some site preparation, fertilization, and weed control. They do require a specialty planter because of the narrow rows and high densities. Although they can be harvested with conventional forestry equipment, they really need a special felling machine to reduce the cost of harvest.

We used 5.1 dry tons per acre per year as the baseline yield. Higher yields have been reported but this represented the average of several studies. As more effort goes into breeding and stock selection, and the improvement of growing systems, it is expected that yield will significantly improve.

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e. Kuzovkina, Y.A., Weih, M., Romero, M.A., Charles, J., Hurst, S., McIvor, I. et al. (2008) '*Salix*: botany and global horticulture', *Horticultural Reviews*, Vol. 34: 447-89.

Southern Pine

Pine plantations are grown across the U.S. but were restricted to the southern pines in this workshop because of their dominance in the number of acres currently being managed and the ongoing efforts to reduce rotation length. The primary species are *Pinus taeda* (Loblolly Pine) and *Pinus elliottii* (Slash Pine), but could include other hybrids. These species grow well almost across the entire southern U.S., especially loblolly, which has a somewhat wider range from Texas to Virginia.

Figure 3-4. Currently, southern pines (primarily Loblolly and Slash Pine [Slash Pine shown in image]) are being grown for sawtimber and pulpwood, but they have great potential as an energy crop or in management regimes that produce biomass and other products. These species grow well across a large portion of the southern United States, on many soil types and levels of moisture, and have been used to reforest many acres of depleted farm land. (Photo courtesy of David South, Auburn University)

Over time, through management science and breeding, southern pines can be grown with very high yields and adapted to many sites and conditions. Plantation management usually includes the planting of superior seedlings, maybe some site preparation, competition control, and fertilization at planting and even in some cases during the rotation.

Loblolly pine will probably be the species of choice as it has the most investment in variety development and enhancing the growth, form, and disease resistance traits through clonal development. Current yields range from 3.5–5.5 dry tons per acre per year. We used 5.5 dry tons per acre per year for the baseline. There are efforts underway to reduce rotation length as low as 15 years with yields almost doubled. Whether they will be used for energy and even with shorter rotations is not known. There is new research to help determine the economic optimality of southern pine plantations under different management schemes and rotation lengths.

Eucalyptus

Eucalyptus spp. has been widely commercialized in the tropics and subtropics and been produced commercially in Florida since the 1960s Eucalyptus yields are influenced by precipitation, fertility, soil, location, and genetics. We used 6.0 dry tons per acre as our baseline, but yields of more than double that are already being reported and are expected in the future in southern Florida. Eucalyptus is grown from seedlings. Other than that, they have the same management and harvest practices as the poplar. A question is the extended range in the U.S. and productivity across more sites. In anticipation of an increased role in biomass production, ongoing efforts aim to develop eucalyptus cultivars for improved yield and frost resistance in the Southern US.

Figure 3-5. Eucalyptus is the world's most widely planted hardwood species. Its fast, uniform growth, self-pruning, and ability to coppice make it a desirable species for timber, pulpwood, and bioenergy feedstocks. (Photo courtesy of Cargill Inc., © 2010 Cargill Incorporated / P. Chandramohan)

WEC Baseline Yields

The baseline yields for WECs were taken from literature as a composite across multiple site studies and are shown in Table 3-1.

Table 3-1. Currently achievable WEC yields.[f]

Species	Region	Current Ton/Ac/Yr
Poplar	North Central	3.5–5.51
	Midwest	4.5–5.0
	South	3.5–5
	PNW	6.0
Willow	Northeast	5.1
Pine	South	3.5–5.5
Eucalyptus	South	5.5–6.0

Alternate HYS Assumption Discussions

Workshop participants discussed R&D currently underway to improve WEC production yields and to what extent they believed future production improvements could be realized to support an HYS. The alternate HYS assumptions are shown in Table 3-2.

Table 3-2. Workshop 3 – Woody Energy Crops (WECs) alternate HYS assumptions.

Discussion	Alternate Assumption
Yield	Average SRWC yields will increase beyond current sustained yields.
Land Use	Land for new dedicated short-rotation woody energy crops will come from existing cropland and pasturelands.
Environmental Sustainability	The rate of additional adoption of short-rotation woody crop plantation management sustainability practices will exceed projections, and innovative new strategies will emerge, both leading to increased woody biomass crop planting rates and management while maintaining environmental quality.
Economic Viability	Economic conditions will incentivize production of short-rotation woody crops.
Other Technology/Policy Advances	Other technologies, research initiatives, and policies that will impact future woody energy crop production are identified.

f. Wright, LL. 2010 submitted. Short Rotation Wood Energy Crops: History of Development and Current Status. Oak Ridge National Laboratory, 2010 (forthcoming).

3.1 Alternate HYS Assumption – Yield

Average WEC yields will increase beyond current sustained yields.

The objective of the first alternate assumption discussion was to identify the issues constraining and supporting the HYS and project the likely rate of yield increase percentage that could be realized with genetic advancements and management innovations on the horizon. The discussion focus was to assess what increased yields are technically possible with genetic advancements and management innovations; thus market drivers, supply/demand influences, and other economic reactions were excluded from the yield potential discussion and explored separately.

Limiting Factors

Participants identified a number of barriers, or "limiting factors," constraining WEC yield. Participants discussed a number of common barriers to the development of WECs of interest for this workshop (willow, poplar, pine, and eucalyptus).

Planting Stock

Planting stock currently available for these crops is limited by genetic development, quality, and availability.[1,2] Factors that contribute to this limitation include slow research and development cycles for WEC species,[3] lack of transgenics to improve yields[4,5] and effective early selection tools,[6] and lack of sustained government and industry support for crop development.[7]

Markets

The viability of a WEC market is also threatened by the costs associated with regeneration methods,[8,9,10] lack of effective production systems and technologies,[11,12,13] lack of understanding of cultural techniques[14,15,16,17] and long-term environmental impact,[18] and lack of understanding of regional growing limitations of each crop.[19,20,21,22] Continual emergence of new pests and diseases also put achievement of WEC HYS yields at risk.[23]

Limited or no access to markets,[24,25] lack of integration with other forest product production,[26,27] and risk of negatively impacting pulpwood markets and jobs are also limiting factors.[28,29] Landowner uncertainties about costs and future policy and regulations, [30,31,3233,34] may limit participation in WEC production.

Assumption Enablers

The limiting factors were used to brainstorm solutions, or "assumption enablers," that might support increased yields and the HYS assessment. A broad range of promising approaches and needed advancements were suggested that fall under a number of different R&D and policy arenas.

1. **Pursue molecular genetics and transgenics to develop new and improved varieties, lines, and families**

Promising crop development research objectives to support the HYS[35] include testing families already developed to expedite release of new varieties and expand the number of species and hybrid clones being developed,[36,37,38] development of varieties with better nutrient-use efficiency and drought and frost tolerance,[39,40,41,42,43,44,45] development of varieties with natural pest and disease resistance,[46] development of advanced-generation pedigrees, and establishment of large association studies to identify candidate genes controlling desired traits. [47,48,49] Research on transgenic clones is needed to identify and confirm which genes control yield.[50,51] Other transgenic work should include research on sterility and gene escape, including flower control,[52] limiting inadvertent gene escape by generation of sterile plants,[53] and demonstration of these controls.[54]

Increasing public understanding and national support of genetically modified organisms (GMOs) will be critical for this development.[55] It will be important to effectively communicate with the public to identify what they perceive as risks of WEC development[56] and provide education on the realistic consequences and benefits of the use of cisgenic clones.[57] One conversion-interface consideration stemming from increasing species yield in general is to evaluate the value of the end product by species not just dry matter yield.[58]

Detailed testing needs to be performed in the regions where the species will be grown so that regionally favorable clones can be selected for deployment and matched based on environmental conditions such as soil pH, texture, and depth.[59,60] Studies on performance of genotype in less that optimal management regimes are also needed.[61]

Some species-specific solutions were presented:

- **Poplar** – A coordinated effort is needed to organize and assess poplar germplasm development work that has already occurred and develop base populations.[62,63] Capitalizing on heterosis based on species used as parents is very important. Basic research on incongruity issues is needed and can ultimately help to increase the probability of selecting favorable progeny.[64] Campaigns to educate about the safety of generation and field testing of cisgenic poplar clones are also needed.[65] Additional work should be performed on poplar to increase drought tolerance.[66] For better site matching and extended growing areas, work should be performed to develop plastic poplar clones.[67]
- **Pine** – Work should be accelerated on the Pine Genome Initiative,[68] and vegetative propagation methods improved for pines and other tree species that are difficult to propogate.[69]
- **Eucalyptus** – Genetic modifications to eucalyptus to allow it to thrive in colder environments will enable fast growing biomass trees to be developed to support the increased demand for biomass and wood.[70,71]

2. **Research and develop management strategies and technology advances to support increased yields**

- **Field Management**

Large field trials are needed with herbicides and fertilizers to maximize plant production,[72] plant spacing/density and other silviculture requirements specifically for bioenergy crop production,[73,74,75,76,77,78,79,80] and coppice management.[81] Site-specific, integrated management schemes need to be developed.[82] Intercropping studies show particular promise in supporting increased yields and can increase more natural nitrogen capture and release to SRWCs,[83,84] capture growth potential during early years of SRWC establishment,[85] or integrate a high-value crop (i.e., saw logs) with an energy crop.[86]

Rotation studies should also be performed to evaluate the impact of rotation length[87] and plant spacing/density on yield curves[88,89,90] and harvest systems[91] to determine optimal growth/ac/yr rates for all species planted[92] and develop reliable process-driven growth projection models.[93]

- **Nutrient-Use Efficiency and Plant Stress Management**

Large, long-term fertilization and soil management studies are needed to better understand the balance between nutrient inputs, removals, movement, fixation, and availability,[94,95,96,97,98,99,100,101] particularly on marginal lands.[102,103] Impacts on the ecosystem, including competing plants, should be part of this analysis.[104] These studies should also include phytotechnologies that incorporate waste management (the integrated use of other biosolids and residuals, such as ash from boilers, as a supply of nutrients[105,106]) with intensive forestry, perhaps using wastewaters as fertilization and irrigation for the trees.[107,108]

Management of pests, disease, and invasive species will be critical as WEC markets emerge and production increases.[109,110] Research is needed for monitoring and responding to these outbreaks.[111,112]

Precision agriculture and forestry management technologies should be developed to provide real-time, site-specific monitoring of nutrient condition for better timing/rate of application.[113,114] This can be very powerful, especially if it then enables clones to be matched to micro-environments within the field.[115] Low-costs methods (i.e., remote sensing) to quantify growth rate and standing inventory would be helpful.[116] Basic research in monitoring/sensing should also work towards identifying biomass properties and plant response to support precision input applications.[117] New concepts in ectomycorrhizal inoculants and remineralization should also be considered, such as root dipping at the time of planting to reduce needed fertilizer input.[118]

- **Production Systems**

Technological advances in nursery production are needed to reduce seedling cost of advanced planting stock.[119] Specifically for eucalyptus, advances are needed to clean and efficiently handle eucalyptus seed and work on cloning eucalyptus, and seed orchards need to be developed for fast-growing trees.[120]

Harvesting systems need to be developed to optimize costs, minimize harvesting losses, and minimize impact on the site and the next coppice rotation.[121] Advancements might include low-impact harvesting and integrated harvesting equipment (combine-like machines).[122] Whole tree extraction systems should also be explored to capture larger biomass volume from the same planting area.[123,124]

- **Competition Management between Species**

Increased understanding is needed to effectively manage competition between species in the growing environment.[125] This includes the spacing and thinning,[126] aboveground and belowground competition, and their effects on yield.[127] Weed competition dynamics are particularly important for determining the level of weed management to be applied.[128,129]

Weed management is challenging because currently available herbicides are not labeled for use with WEC:[130] thus better labeling is needed.[131] WECs are a good candidate for more flexible labeling requirements than are currently used for herbicides applied to food crops.[132]

- **More Efficient Site Utilization**

One area that will enable greater efficiency in site utilization while maintaining soil productivity is increased understanding of the impact of biomass removal on nutrient cycling and carbon pools when additional biomass (i.e., foliage, branches, roots) is removed from the site.[133,134,135] Total utilization of site production includes WEC stumps, which, for pines, can provide up to 21% more volume.[136] Technology exists for stump extraction, but it may not be cost effective.[137] Integrating stump removal with site preparation may offset some of these costs.[138] Stump usage also introduces biomass material that is contaminated with dirt and rocks into the supply chain, which will need to be addressed with equipment modifications and other engineering, such as development of conversion technologies that are less sensitive to contamination.[139,140]

Developing multiple product streams from the crop or site can increase efficiency of site utilization, support environmental sustainability[141,142] and economic viability,[143] and thereby encourage participation in SRWC production and increase biomass available for the HYS.[144] Genetic engineering can enhance the production of valuable co-products as genes are being identified that regulate the production of these metabolites.[145] Research needs to be conducted that better characterize these metabolites in different tissues of various woody crops and specific clones.[146] Auxiliary studies should seek to determine the impact of SRWC age on these co-products[147] and identify costs of producing and marketing multiple products from these systems.[148]

- **Education**

Education on the uncertainty and risks of SRWC production and how to reduce these uncertainties to within tolerable levels is needed to stimulate participation. This will be an important element of incentive programs targeted at cooperatives and other producer groups.[149] Generational educational strategies designed for student populations ranging from early primary to graduate-level are also needed to communicate the environmental benefits of production forestry in relationship to larger ecosystem management strategies.[150]

3. Bridge research gaps between genetic breeding and applied programs and integrate research programs

Genetic breeding may help expedite release of clones;[151] however, testing of large-scale breeding programs to develop commercial clones may not meet the needs of the molecular genetics community because large-scale genetic tests are short-term and can quickly become irrelevant.[152] Molecular genetics program needs should be identified so that long-term breeding, genotypic screening, clonal trials, and yield trials are supported.[153]

Basic and applied research programs should be integrated to support a holistic, systems-based research approach. Analysis of interdependent issues, such as nutrient management, spacing, rotation length, pest and disease management, soil loss, and weed management will help research identify the elements of greatest impact to the overall system.[154] The integrated research portfolio should include short-term applied objectives balanced with longer term (7 to 8 years[155]) basic work, including genetics, silviculture, and harvesting.[156]

Regionally distributed,[157] long-term, large-scale, multi-site yield trials over multiple rotations are needed[158,159] to examine potential growth of species[160] and performance under a variety of growing conditions.[161] These studies need to cover a range of soils and climate conditions.[162] Methods and tools for making informed decisions on where to test and deploy genotypes are needed to help increase plantation success and ultimate yield.[163] In addition, true yield-blocking trials are needed to test the productivity of clones without competition of other genotypes.[164]

Yield models based on the results of these trials are needed to support both national and project-specific needs.[165]

Projecting Future Yield Improvement

There is much less historical yield data available for estimating potential WEC yield improvement than for agricultural row crops like corn. Participants provided input based on their areas of expertise and understanding of the land resource regions (Figure 3-6) most appropriate for specific woody crop production (Figures 3-7 through 3-10). They were asked to provide input only for the crops and regions they had understanding of, and the variety of their backgrounds is apparent in the ranges projected for each crop.

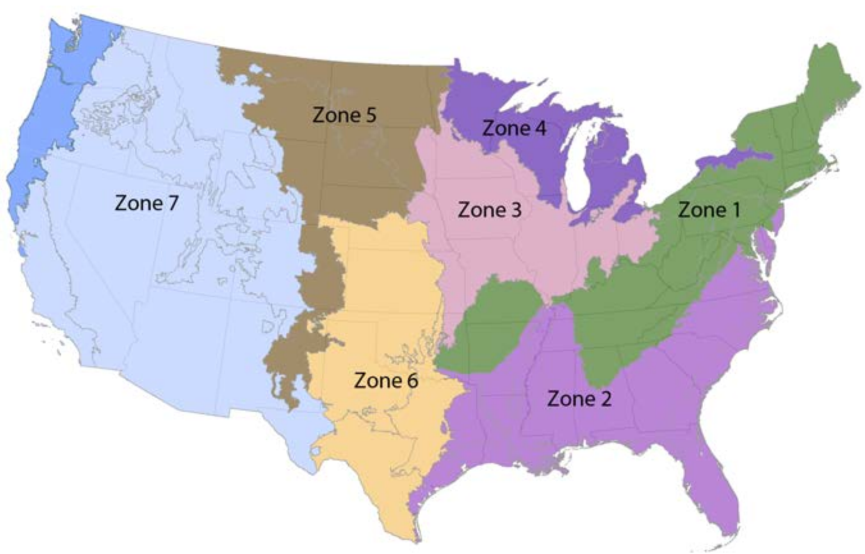

Figure 3-6. *Land resource regions used to estimate current yields of WECS (adapted from USDA-NRCS [2006]).*[g]

g. USDA-NRCS (2006) Land Resource Regions and Major Land Resource Areas of the United States, the Caribbean, and the Pacific Rim, USDA Agriculture Handbook 296.

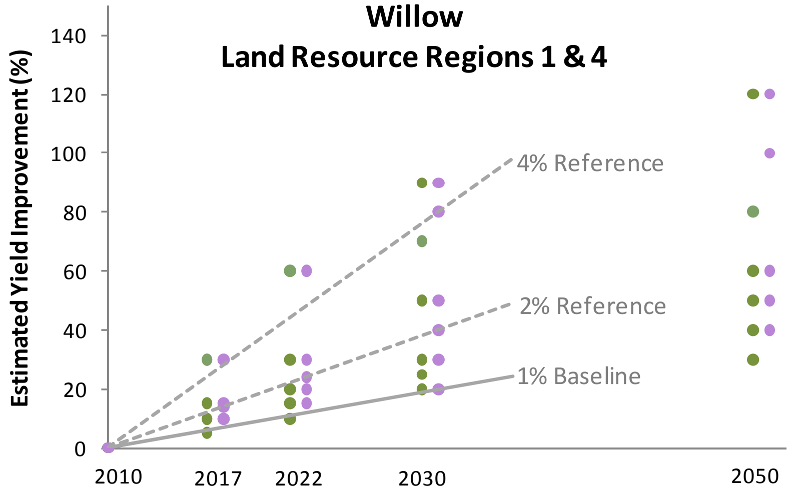

Figure 3-7. A scatter plot of participants' projections of % yield improvement for willow indicates a conservative concern regarding limiting factors that must be overcome to achieve the HYS (dots near the lower dashed line indicating the baseline 2% annual yield improvement) and more optimistic projections that these barriers will be successfully overcome and support 4% and greater annual yield improvement.

Table 3-3. Willow – number of voters and voter consensus (VCC) for Regions 1 and 4.

Consensus	# of Voters	2017	2022	2030	2050
Land Resource Region 1	6	0.89	0.78	0.72	0.67
Land Resource Region 4	5	0.90	0.78	0.70	0.66

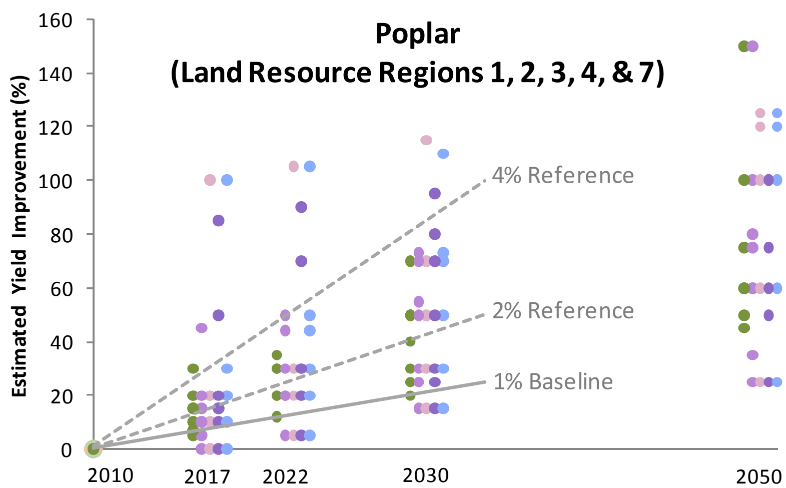

Figure 3-8. A scatter plot of participants' projections of % yield improvement for poplar indicates a conservative concern regarding limiting factors that must be overcome to achieve the HYS (dots near the lower dashed line indicating the baseline 2% annual yield improvement) and more optimistic projections that these barriers will be successfully overcome and support 4% and greater annual yield improvement.

Table 3-4. Poplar – number of voters and voter consensus (VCC) for each Region 1, 2, 3, 4, and 7.

Consensus	# of Voters	2017	2022	2030	2050
Land Resource Region 1	7	0.92	0.94	0.85	0.63
Land Resource Region 2	8	0.86	0.85	0.78	0.61
Land Resource Region 3	6	0.64	0.65	0.65	0.61
Land Resource Region 4	7	0.70	0.69	0.70	0.71
Land Resource Region 7	6	0.66	0.67	0.66	0.58

Figure 3-9. A scatter plot of participants' projections of % yield improvement for pine indicates a conservative concern regarding limiting factors that must be overcome to achieve the HYS (dots near the lower dashed line indicating the baseline 2% annual yield improvement) and more optimistic projections that these barriers will be successfully overcome and support 4% and greater annual yield improvement.

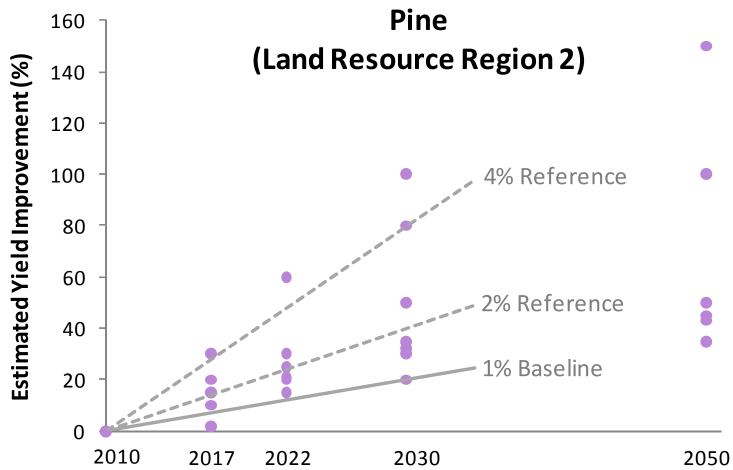

Table 3-5. Pine – number of voters and voter consensus (VCC) for each land resource region.

Consensus	# of Voters	2017	2022	2030	2050
Land Resource Region 2	7	0.91	0.85	0.70	0.57

Figure 3-10. A scatter plot of participants' projections of % yield improvement for eucalyptus indicates a conservative concern regarding limiting factors that must be overcome to achieve the HYS (dots near the lower dashed line indicating the baseline 2% annual yield improvement) and more optimistic projections that these barriers will be successfully overcome and support 4% and greater annual yield improvement.

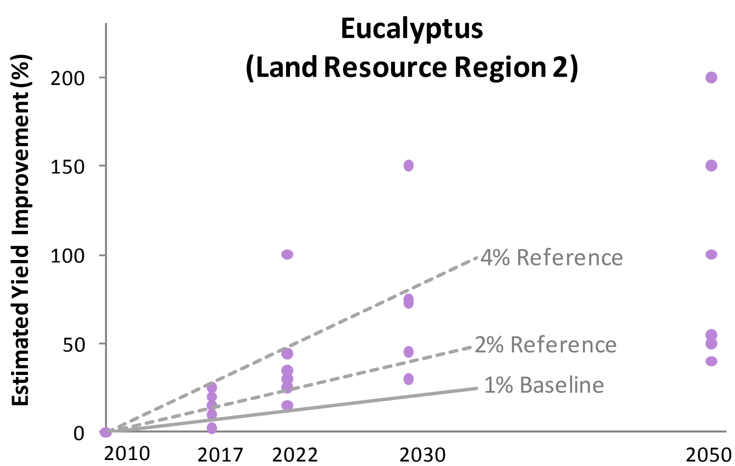

Table 3-6. Eucalyptus – number of voters and voter consensus (VCC) for Region 2.

Consensus	# of Voters	2017	2022	2030	2050
Land Resource Region 2	6	0.92	0.70	0.55	0.36

3.2 Alternate HYS Assumption – Land Use

Land for new dedicated short-rotation woody energy crops will come from existing cropland and pasturelands.

Limiting Factors

The land-use barriers identified to achieving the Alternate HYS Assumption fall into three general areas: land ownership objectives, economics, and policy.

Land Ownership Objectives

Traditions in land use established over generations may discourage participation,[166] and landowners' motivations will vary depending on a number of factors, such as whether they manage the land or not.[167] Changing land use from production of traditional agricultural crops, pasture, forest land, or other uses may be set back because of the paradigm shift of working with SRWC.[168] Agricultural landowners may be unfamiliar and uncomfortable with tree culture and management.[169] Longer rotations may be more popular for some landowners,[170] and current forestland owners may opt for pine SRWC (which has a 12-year rotation) rather than hardwood (which has a 3-year rotation) because it is more like a forest.[171] SRWC may not provide enough other intrinsic values to a land owner, such as wildlife habitat, and it may be perceived as too much of a monoculture compared to forest land.[172,173]

The compatibility of SRWC and landowners objectives must be weighed out,[174] including potentially conflicting objectives in the protection of biodiversity, water quality, and soil conservation.[175] The lack of understanding of the biodiversity benefits of SRWC is a barrier to deployment.[176]

There is also a misperception that woody crops can be grown like conifers planted in old fields,[177] and that forestland will be converted to SRWC and lost, [178] which is not what is being proposed.[179] Knowledge and education of landowners about their participation options and the long-term impacts on the landscape and production will be important.[180]

Economics

1. Establishment Cost, Return-on-investment (ROI) Timeframe, and Contracts

Land-use change supporting increased production of SRWC will depend on the financial ability of landowners to invest[181] and the best economic return for their investment.[182] High upfront costs for establishing woody energy crops and length of time until an economic return is realized will discourage landowners from planting trees.[183,184,185,186]

Because much of the land appropriate for SRWC production is owned by small landowners, short-term returns will be important for incentivizing them to plant.[187] In addition, long-term contracts with end users will guarantee acceptable ROIs and reduce risk.[188] Long-term contracts referenced to cost indexes are not mainstream, which will raise risk for landowners.[189] These contracts cannot simply be based on net present value (NPV); they also must address cash flow objectives and capabilities of private landowners.[190]

2. Supply and Demand Dynamics

Local markets to drive demand for SRWC are currently limited[191] and based on proximity to a biomass energy facility.[192] Larger future markets are uncertain,[193] which may cause landowners to hesitate to invest or agree to engage in producing a long-term crop.[194] Producers are looking for multiple use cropping systems.[195] They will find the best ways to make money from their land, and switching crops in anticipation of expected markets is common. If producers are provided a market to take their biomass to and receive a financially attractive price, they will participate.[196,197] Stable biomass markets will motivate landowners.[198]

3. Market Price and Competition of Other Markets

One of the driving forces for land-use change will be the selling price producers can get for their biomass. SRWCs are perceived to be a low-value added resource[199] that provides low financial returns to the land owner.[200] If producers are provided a market to take their biomass to and receive a financially attractive price, they will participate.[201,202] They will find the best ways to make money from their land, and switching crops in anticipation of expected markets is common.

Land-use change supporting SRWC production will also be impacted by competition from other woody resource markets, for example, pine saw timber.[203] The relative prices of livestock and pulpwood will be a key factor affecting feasibility of growing SRWC on pasture land.[204] Some important mitigations necessary to make SRWC competitive with other markets and land-uses are major yield improvements,[205] a definition of what the yield function looks like[206] (will be different than agricultural crops[207]), and greater certainty of the reliability of increased SRWC yields.[208]

4. Parcel Size and Proximity to Conversion Facilities

Operating costs are significantly impacted by parcel size,[209] and small parcels may not have scale necessary for practical application of technology.[210] Conversion facilities also will be drawing from increased transportation distances,[211] which increase logistics costs. Depending on end use, these could be offset with modular, bioregional facilities.[212,213] Location of biomass facilities nearby reduces costs and raises prices paid for biomass. Aggregation of sources can result in higher density-of-use facilities and lower transportation costs.[214] Another potential response to mitigate this economic barrier is to develop alternative types of biomass facilities from the present mass burn mentality.[215]

Policy

Policy-related concerns will have significant impact on land-use changes that will support SRWC production. From incentive programs[216] to tax reform to agricultural trade policies and legislative definitions of renewable biomass,[217] policy developments will dictate the role of SRWC in the high-yield scenario.[218]

Tax reform is a key to sustainable forestry and expansion of woody biomass supplies.[219] Cost depletion schedules would need adjusting to make longer-term capital investments more competitive with agriculture alternatives.[220] Real estate investment trusts (REITs) and timber investment management organizations (TIMOs) drive ownership and reduce integration of products sources and utilization.[221]

Assumption Enablers

The limiting factors were projected on a screen to use as a guide to brainstorm solutions, or "assumption enablers," that might support increased yields and the HYS assessment. A broad range of promising approaches and needed advancements were suggested that fall under a number of different R&D and policy arenas.

1. Transition poorer land capability class (LCC) lands into use

A number of land-use changes could potentially support the HYS, including production of SRWC on poorer quality lands (i.e., Class II cropland – buffer strips, abandon farmland, pasture lands).[222] Agricultural landowners, who are accustomed to crop management, will be likely to move some pasture land as well as marginal agricultural land into SRWC production.[223] Non farmers may want higher quality land in SRWC.[224] If the economics are supportive, forest lands will be converted to SRWC like eucalyptus.[225]

The HYS could include the lower Mississippi alluvial valley as potential hardwood SRWC production,[226] as well as woodlands in the western United States (i.e., Poplar in East Oregon).[227] Utility right-of-ways (ROWs) could also be included for production of SRWCs that are relatively short in height crop and harvested frequently.[228]

2. Assess and mitigate land-use environmental concerns

National public policy debate over land-use change for bioenergy production is a substantial barrier to the HYS. Land-use change strategies that support SRWC production must demonstrate environmental sustainability and accommodate various land-use priorities (i.e., wildlife, natural forest ecosystems, nutrient cycles, water quality, diversity, wilderness areas).[229] One such land-use priority is to maintain the ephemeral habitat cover for wildlife diversity, which may or may not be accomplished with willow SRWCs.[230] Long-term water quality may also be impacted, and fertilizer response (nitrogen in particular) needs to be determined and comparisons made among various cropping systems (pasture, corn, woody crop).[231]

3. Define the role of public lands in SRWC production

Public lands (i.e., U.S. Forest Service, BLM, state, and local government) are currently deterred from SRWC production because of the highly constrictive way renewable biomass is defined in legislature. Some believe that biomass production on public lands is unlikely to happen,[232] and public lands should not be included in forest availability assessments unless federal and state agencies change policy to allow woody biomass from public lands to support the green energy demand[233,234] and let them count toward Renewable Fuel Standard (RFS) credits. Public land managers may be able to impact this and need to have clear priorities, with production of commodities among them.[235]

4. Develop policies that incentivize participation

- ***Tax policies* –** Tax policies can have a high impact on participation, especially policies that give growers immediate credit for site preparation and planting costs, which should be considered as expenses rather than capital investments that must be recovered over a longer depletion schedule (similar to the Soil Bank Program, the Conservation Reserve Program [CRP], and past successful tree planting programs).[236,237,238] The Biomass Crop Assistance Program (BCAP) is a model for this on a limited basis (pays 75% of planting in BCAP zones).[239] 100% tax credit for site preparation and planting of crops will have an immediate return: site preparation contractors will be at work immediately, nurseries will be planting trees because they have orders, and land owner/managers will be planting biomass. This would require no USDA staff to administrate and little paperwork for the government because the incentive is handled via tax return.[240] This would require that a consistent, flexible, and reasonable definition of renewable biomass be adopted in relevant legislation.[241]
- ***Carbon credit policies* –** There are many aspects of carbon accounting that can benefit both the environment and the SRWC industry. Carbon capture storage annual revenue streams could be leveraged to help offset supply chain costs. [242] The residual biochar from pyrolysis of woody materials used to produce liquid fuel should qualify as permanently fixed carbon, enabling SRWCs to serve as "carbon scrubbers."[243] Clear and accurate policies and regulations will need to define the carbon benefit of SRWC on a level playing field with other renewable energy resources and determine how those credits will be allotted.[244]
- ***Alignment of tax and environmental policies with national objective to increase U.S. competitiveness* -** The forest sector is by far the largest current producer of bioenergy.[245] We need to align tax and environmental policies with national objective to increase competitiveness of U.S. forest sector in global markets for pulp, building products, and biofuels/new biomaterials.[246] We also need to capitalize on opportunities to expand combined heat and power production with biomass at U.S. pulp and paper mills.[247]

5. Develop business models that provide participation options and distribute risk

Because of the duration of rotation, producers will not receive a return on their establishment investment for several years. One advantage of SRWC, in comparison with forestland, is that the recovery of crop is more frequent, which may make the SRWC business model more attractive.[248] Some may prefer longer short-rotation species because there is less labor, and others may like the option of a shorter rotation (i.e., 3 years) because they can change more easily if they do not like how the crop is going.[249]

Distributing risk between producer and end user will further encourage participation.[250] Some ways of accomplishing this are for biomass facilities (and possibly government) to work with landowners by (1) leasing the land, (2) covering establishment and management costs, (3) providing an annual revenue payment in anticipation of the final delivered crop, and/or (4) providing a guaranteed market.[251,252,253,254] Long-term, stable contracts with biomass users,[255] possibly designed like an annuity to create a predictable cash flow for landowners,[256] will encourage participation and reduce risk for both the producer and the biomass user.

There are existing business models that may be adaptable for this industry.[257] Similar to the "Chicken Farm Model," pulp and paper companies in South America who use eucalyptus have a business model where they work with local landowners to provide seedlings, technology, annual payments, and a market for the final product.[258] This business model also works for the seedling provider in a three-way agreement.[259]

Education is an important component for encouraging land-use change to produce woody energy crops. A variety of business models will be needed[260] to provide participation options for producers, and effective educational materials and venues will be needed to communicate those models so that producers can make sound decisions.[261] Landowners will need to understand what is involved with this type of cropping and harvesting,[262] and biomass facilities will need to understand that they have to develop a business model that recognizes the needs of the landowners for annual payments and a confirmed market.[263]

6. Use remote sensing to identify idle acres

Remote sensing could be used to identify idle acres. This idea is currently being expanded upon by the development of a GIS-based spatial analysis protocol to identify candidate core areas where SRWC can be tested and deployed, and then evaluating soil health, water quality, carbon, and other parameters within those areas. Productivity is also being evaluated within these areas.[264] Once idle acres are identified, landowners could be contacted and encouraged to plant biomass crops. [265] Engaging the landowners, an important social aspect of developing this supply, is often not addressed, and while it may add confusion and complexity to developing these systems, it is essential.[266]

3.3 Alternate HYS Assumption – Environmental Sustainability

The rate of additional adoption of short-rotation woody crop plantation management sustainability practices will exceed projections, and innovative new strategies will emerge, both leading to increased woody biomass crop planting rates and management while maintaining environmental quality.

Limiting Factors and Assumption Enablers

As part of the environmental sustainability alternate assumption discussion, participants were asked to identify the environmental barriers, or "limiting factors," constraining yield. The limiting factors were projected on a screen to use as a guide to brainstorm solutions, or "assumption enablers," that might support environmental sustainability with increased WEC production. A broad range of promising approaches and needed advancements were suggested that fall under a number of different R&D and policy arenas.

1. Provide incentive programs and establish BMPs to support regeneration/planting

One of the most critical limiting factors participants identified is the need for methods to produce SRWCs in a sustainable manner. Landowners may need incentives or contracts for them to consider planting these crops.[267] Site preparation practices for conversion to woody crops need to be developed and refined to address concerns with soil erosion.[268] One possible solution for reducing soil erosion during this transition is to use chemical site preparations versus mechanical site preparation. [269] The impacts of various planting density strategies also need to be analyzed for their effects on wildlife habitat.[270]

2. Foster genetic improvement programs

Genetic improvements can be made on a number of fronts. Selection of varieties and genotypes that are efficient users of nitrogen will enhance environmental sustainability.[271] Transgenesis shows promise for enhancing nutrient-use efficiency, [272] water-use efficiency, and drought tolerance.[273] Genetic modification of organisms (GMOs) may enable expansion of planting zones and increase eucalyptus production ranges.[274] GMOs can also provide solutions for remediation practices,[275] and may be a good alternative for modification of native genes.[276] GMO safeguards are needed to reduce public concerns about the effect on human health, impact on the environment, and societal benefits and risks while ensuring.[277]

3. Develop more sustainable harvest methods

Another enabler is development of low energy consumption[278] and soil sustainable harvest methods. One method for more energy efficient harvesting operations is to develop a system that removes the entire tree (including top and roots) in a single pass.[279] Other harvest system method discussion focused on soil sustainability and how to minimize the effects that site preparation and harvest has on erosion, compaction, rutting, and other soil properties.[280,281] Suggested solutions for reducing soil organics include leaving 30% of organic material in forest,[282] the debarking and redistribution of bark on-site,[283] and leaving the stems behind with the foliage for SRWC harvested during the growing season or harvesting SRWC in the dormant season leaving most of the nutrients on site.[284]

4. Implement integrated cropping systems

Development of integrated cropping systems provides a more sustainable ecosystem compared to a monoculture ecosystem.[285] Options for integrated cropping systems include interplanting SRWC with compatible grass or grain species[286] and planting SRWC in corners of agricultural land.[287]

5. Develop innovative landscape-scale management strategies

Determining efficient landscape management practices enables higher yields while continuing to address the issue of soil sustainability. Several options were discussed on how to enable more efficient, higher yielding landscape management practices. Using biotech and precision forestry methods on soils well suited for SRWC and intensive management creates the potential for increased yields.[288] Another option for increasing woody production is to reintroduce woody crops into appropriate agricultural areas.[289] In some cases introducing SWRC in to agricultural areas creates a more sustainable ecosystem[290,291,292] and may improve overall productivity of the land.[293] SRWC strategically placed provides a landscape with the ability to recycle nutrients and maintain genetic diversity relative to previous land use systems.[294] Another suggestion to produce more woody biomass is to utilize SRWC in public corridors such as underneath power lines, road medians, and shoulders.[295,296] SRWC also has the ability to create corridors and connect fragmented landscapes,[297] such as longer rotations in streamside management zones.[298] Looking at the overall system, landscape management practices could utilize waste from one system to help development of another system. For example, ash from a boiler could be used as fertilizer for energy crops or wastewater from a pulp mills could be used to irrigate energy crops.[299]

6. Incorporate use of biosolids into production systems

It is not uncommon with intensive forestry to incorporate biosolids from waste management such as landfill leachates, paper mill sludge effluents, and septage effluents.[300] The use of biosolids provides a source of nutrients and organic matter that can increase productivity and help maintain soil quality.[301] Incorporating biosolids into land management practices can help reduce the amount of commercial N fertilizer applications by 50% and can dramatically reduce the production of GHG.[302] Using biosolids for woody crop production also provides an alternative option for mills and municipal facilities to dispose of their waste,[303] which could reduce the amount of subsidies required to make biosolids a viable replacement for N fertilizer application. Another benefit of using biosolids on woody crops is that they remain out of the food supply.[304] The value of the added nutrition may not cover the costs of transportation and application, but the fee paid for waste disposal may help offset the difference.[305]

7. Conduct further research on residue management

Residue management is important for determining what forest residues look like, how they are stored, and how much should be left. Forest residues can come in many forms. Stumps can be used for bioenergy and while some people have concerns about using stumps as a resource for bioenergy due to nutrient loss, it is likely that regardless nutrients will have to be replaced.[306] Tree tops are another form of forest residue. An efficient method of processing tree tops is to bring them to the ramps and having them topped so they can be ground or chopped on location.[307] Another aspect of residue management is being able to handle the surge of residues due to the SRWCs short harvest window and having the proper storage infrastructure in place.[308] And while the SRWC harvest window is short, it is actually relatively long compared to other agricultural energy crops.[309] Technologies for estimating the amount of residue retention need to be developed instead of using blank guidelines.[310,311] With these new technologies, producers will have the knowledge necessary to redistribute residues in concentrated areas to those areas low in nutrients.[312]

8. Leverage precision agriculture systems and monitoring

Another enabler is developing the best management practices for precision forestry[313] that can monitor, respond, and adapt to any adverse changes.[314] Through precision forestry, application of fertilizer, pesticide, and herbicide should be minimized.[315,316]

9. Tailor best management practices to new short-rotation crops

When developing best management practices (BMPs) for SRWC systems there are many things that need to be considered. BMPs should be developed for SRWC systems on a regional basis as landscapes, local policies, and resources will differ.[317] To address these regional issues, BMPs should consider developing site preparation protocol to minimize erosion potential and nutrient loss by developing reduced tillage methods and incorporating cover crops[318,319] as well as a long term plan that includes changing systems to help reduce runoff.[320] BMPs should also address water management issues[321] and the physical limitations of the soil[322] to enable land productivity. BMPs should adhere to harvesting guidelines set forth in Federal and State policies which will differ from guidelines for agricultural systems.[323] Carefully thought and consideration should be given when developing BMPs as excessive or random BMPs have the potential to increase costs beyond sustainability and profitability.[324]

10. Address soil properties that limit productivity

Soil properties, including nutrient levels and carbon content,[325] can limit the productivity of soil. Using N-fixing and deep-rooted N cycling species can enhance nitrogen availability,[326] while further research is needed to determine carbon sequestration in woody crops.[327,328] This is very difficult, especially for belowground tissues, but is being actively pursued in the Lake States as part of the development of a regional model for carbon sequestration of SRWC.[329] Harvesting operations that broadly improve site productivity through tillage practices or soil amendment could be incorporated.[330]

11. Identify and communicate the benefits and challenges of SRWC production

The advantages of SRWC over agricultural rotations need to be communicated to the public and concerns about sustainability with SRWC systems need to be addressed.[331,332] One advantage is that woody species should be easier to track and inventory.[333] SRWCs can also be used in bioremediation regimes for agriculture and mine land reclamation. Sites must be analyzed individually and plans formulated to address site-specific contamination concerns and identify the best woody species to produce on the site.[334]

Large swaths of mountaintop coal mines and strip mine reclamation could lend themselves to SRWC if appropriate species can be identified.[335,336] Popular and willow are good candidates for phytotechnologies, but more studies need to be conducted on where contaminants are stored in the woody tissue.[337] Biorefineries using material from mine land reclamation sites would require special processing to extract toxins absorbed by the trees for proper disposal.[338]

3.4 Alternate HYS Assumption – Economic Viability

Economic conditions will incentivize production of short-rotation woody crops.

Limiting Factors and Assumption Enablers

As part of the alternate assumption discussion of Economic Viability, participants were asked to identify the economics-related barriers, or "limiting factors," that prevent producers from becoming actively engaged in dedicated SRWC production and selling, and thus constrain establishment of a commodity-scale market for woody energy crops.

The limiting factors were projected on a screen to use as a guide to brainstorm solutions, or "assumption enablers," that might support the HYS. A broad range of promising approaches and needed advancements were suggested that fall under a number of different R&D and policy arenas.

1. Increase efficiency in crop regeneration/planting systems and biomass harvest systems

Increased efficiencies in production and supply chain logistics are critical for the economic viability of SRWC for feedstock. A systems approach is needed to increase yield and minimize costs as evaluating system components in isolation will often miss opportunities for some synergy.[339] Development of improved, cost-efficient planting stock production systems[340] and mechanization of planting stock preparation and handling[341,342] are two promising advances to pursue.

Harvesting system development also has promising opportunities. Harvesting systems that can be used across a wide range of both agricultural and SRWC systems will maximize the acres covered and tons produced by a single unit and thus distribute capital costs across more tons of material.[343] Actual yield can increase as system advances minimize material losses through improved recovery efficiency of harvesting, processing, and transport[344] and maximize bulk density by reducing water content in the biomass. Development of in-field processing operations to improve feedstock drying and chipping,[345] and development of harvesting systems that can work in a wider range of weather conditions,[346] crops, and production systems[347] also have the potential to expand SRWC's role in the bioenergy feedstock market. Other promising advances include single-pass systems the cut, strip, chip, and dispense from a combine;[348] continuous-travel felling equipment;[349] tracked systems;[350] and systems optimized for fuel efficiency.[351]

2. Identify the optimal rotation, management practices, and crop type for the environment

A better understanding of optimal rotations for a variety of priorities, depending on the intended end use,[352] and the relationship between site quality and yield,[353] will support environmental sustainability by minimizing soil compaction and nutrient depletion,[354] enabling site quality to be matched with plant variety.[355] Understanding the impacts of spacing on the SRWC[356] and the value of storing biomass on the stump[357] would be beneficial in finding an optimal output and rotation based on the inputs available, such as sunlight. Agricultural extension will play an important role in assisting producers through the learning curve of transitioning to new crops.[358]

3. Reduce inputs

A better understanding of fertilization response by site is needed to maximize impact of fertilizer application.[359] More is not always better, thus we need to optimize yield for economics rather than maximize it.[360,361] Transgenic herbicide-resistant trees can enable more effective use of herbicides and reduce costs as well.[362] Another potential way to lower input costs is to use inputs such as waste streams (organic amendments) rather than commercially produced fertilizer and other innovative fertilization methods that reduce the environmental footprint.[363,364] These may be provided to producers at low cost or free to make the economics of SRCW viable.[365]

4. Increase yields

Genetic improvement has the potential to increase yields in a number of ways. Robust, high-yielding clones with demonstrated performance through a national breeding and field testing effort is necessary for increased yields.[366] Selection of favorable genetics during these field tests,[367] and employing gene stacking to introduce multiple candidate genes and enhance productivity traits in clones that already demonstrate high productivity,[368] can produce high-yield crops. Genetic improvement should also be used to enhance drought tolerance[369] and resistance to disease and pests.[370] Transgenics can be used to transfer the best genes in one species to enhance another species to produce the optimal yield.[371] Development of species that can be harvested during a wider time period without adversely impacting regeneration will provide benefits on many fronts and allow producers more flexibility to manage other production enterprises.[372]

5. Improve business profitability

To increase the supply of the SRWC for biomass, the burden of risk needs be shifted in part from the producer.[373] This could be accomplished through development of efficient business structures with up-front lease payments similar to oil and gas leasing[374] or long-term, annuity-like contracts indexed to costs/price indexes.[375] These long-term agreements would include structured, guaranteed payment systems, such as annual payments provided by biorefiners to producers, for future or existing crops.[376,377,378]

Because of the risk of longer rotations (5 to 10 years), biomass crop insurance could provide some risk mitigation for producers and incentivize them to participate.[379] Timing harvest to maximize market prices, volume, and marginal gain, rather than according to a fixed rotation, can improve producers' return on investment.[380] Biomass value (and profit) for both the producer and end user could be increased by producing multiple products from each ton of biomass.[381,382]

6. Develop in-field processing systems to reduce transportation and handling costs and enable long-term storage

There are many opportunities for improving the efficiency of woody biomass transportation. The high moisture content of most woody species (approximately 50% after harvest in most regions) reduces truck capacity and decreases the amount of dry matter transported. Developing crops with lower water content at harvest will help increase transportation efficiency.[383] In-field processing systems that reduce moisture and increase density[384] (such as using transpirational drying) could increase the amount of material that can be moved in each truck and reduce transportation costs[385] and give the material aerobic stability for longer storage.[386] Having the ability to store woody biomass for longer periods will help reduce market price fluctuation,[387] and integrating biomass supply from multiple sources over the year will reduce storage costs.[388] Bundling these with long-term storage could increase energy yield as well.[389] New truck designs could increase the payload while not compromising mobility at the landing, and improved loading techniques and process layout could enhance equipment utilization.

3.5 Alternate HYS Assumption – Other Technology/Policy Advances

Other technologies, research initiatives, and policies that will impact future herbaceous energy crop production are identified.

Concluding discussions allowed participants to present additional thoughts about other technologies, research initiatives, and policies that will impact future herbaceous energy crop availability. Participants were asked for any additional suggestions that had not been presented in earlier discussions sessions, such as technology advances that could enable abundant supply to all biomass markets, suggested federal research initiatives to outline and fund all near- and long-term feedstock production and supply R&D, and policy initiatives to make available the land required to provide an abundant supply of biomass.

Limiting Factors and Assumption Enablers

The discussion was brief, but participants emphasized one important point: tax, trade, and environmental policies need to be aligned with U.S. national renewable fuels goals.[390] This will increase competitiveness of the U.S. forest sector in global markets for wood, pulp, building products, biofuels, and biomaterials.[391] Government support for the initial deployment of SRWC can help in the launch of the bioenergy industry by implementing BCAP with sufficient funding over a long enough period of time to offset risk for early adopting producers and biorefiners.[392]

Workshop Participant Bios

Bill Berguson

Berguson holds an M.S. in Forest Resources from the University of Minnesota. Since 1986, Mr. Berguson has worked as director of Applied Forestry at the Natural Resources Research Institute (NRRI). He developed and manages a program of research in hybrid poplar production, management, and genetic improvement in Minnesota. This program is one of the largest poplar breeding and field testing programs in the world. Mr. Berguson is also chair of the Minnesota Forest Productivity Research Cooperative, which conducts research in hybrid poplar, red pine, and aspen management and silviculture. Research is done in conjunction with major public and private industrial landowners in the region and focuses on stand productivity and management techniques such as thinning and fertilization in red pine and aspen.

Starling Childs

Starling Childs received his M.S. in Forest Science at Yale University in 1980. He is deeply committed to the management of land and natural resources for a sustainable economic future and a healthy environment. Mr. Childs' background in the environmental sciences and practical and professional skills developed from more than 30 years in the field have enabled him to continue his partnership in EECOS (Environmental and Ecological Consulting Services, Inc.) He serves as president of the Berkshire Litchfield Environmental Council and is director, chairman, and member to many other environmental associations.

Mike Cunningham

Michael Cunningham received his Ph.D. in Forest Genetics from North Carolina State University in 1986. A wealth of leadership experience led up to his current job as director of product development at ArborGen, LLC in Tallahassee, Florida. In this position, his responsibilities include directing field operations related to genetic improvement of pine and hardwood species for the ArborGen SuperTree Seedling Nurseries. Dr. Cunningham also directs field operations related to evaluations of transgenic pine, hardwood, and eucalyptus species in the southern United States. He has authored or co-authored several articles and conference papers, the most recent of which is the "Purpose-Grown Trees as a Sustainable, Renewable Energy Source" presentation for the Short Rotations Crops International Conference in 2008.

Michele Curtis

Michele Curtis is the wood supply manager at Buckeye Cellulose/Proctor & Gamble, where she has held numerous positions, including manager of Site Public and Governmental Affairs, company spokesperson for media contacts outside Taylor County in Florida, and leader of biomass development activities for potential biomass energy expansions at the Buckeye plant site. She currently serves on the School of Forest Resources and Conservation Advisory Council at the University of Florida, the Florida Forestry Association Executive Board, Florida Regional Agricultural Advisory Council, and the Frank Norris Foundation (Timber Mart South – timber reporting service).

Howard Duzan

Howard Duzan Jr. holds a Ph.D. in Forestry from North Carolina State University and is presently the manager of Southern Timberlands R&D for the Weyerhaeuser Company in Columbus, Mississippi. In this position, he manages a team of scientists, technicians, and data processors responsible for developing and communicating forest technology for Weyerhaeuser Southern Timberlands. He also serves as the business facing lead for Southern Timberlands, understanding the needs and opportunities for the business and translating those into research efforts. Dr. Duzan specifically directs the work of the Production Forestry research units within Southern Timberlands R&D, which includes productivity, silviculture, and growth and yield. He manages support for Catchlight Energy LLC sustainability and scalability research pathways and is the leader of the Weyerhaeuser Biomass Research project, which conducts in-company work on forest resources as a source of biomass.

Thomas Fox

Thomas Fox holds a Ph.D. in Soil Science from the University of Florida. He is a professor of Forestry for the Virginia Polytechnic Institute Department of Forest Resources and Environmental Conservation. In addition to teaching, his research interests are silviculture and forest soils. Dr. Fox is also director of the NSF Center for Advanced Forestry Systems, a multi-institutional, multi-disciplinary facility focused on creating the advanced technology needed to improve the productivity, profitability, and sustainability of forest ecosystems throughout the United States. He is co-director of the Forest Nutrition Cooperative of Virginia Polytechnic Institute, directing activities of a university/industry research partnership among Virginia Tech, North Carolina State University, and the University of Concepción in Chile, whose research and technology transfer activities are focused on developing precision silvicultural regimes that optimize the productivity and financial returns from plantation management of southern pine, Radiata pine, and eucalyptus for member companies in the U.S. and South America.

Rob Harrison

Robert Boyd Harrison holds a Ph.D. in Soil Science from Auburn University and is a full professor at University Estadual de Sao Paulo in Brazil, having previously served as an adjunct professor at this institution. Prior to this, Dr. Harrison was the Nutrition Research Project coordinator for Northwest Stand Management Cooperative and Professor Titular (highest rank) in the Forest Engineering Department at the Federal University of Viçosa, Minas Gerais, Brazil.

He has co-authored many publications, the most recent of which are "Controls on the Sorption, Desorption and Mineralization of Low Molecular Weight Organic Acids In Variable-Charge Soils," "Nitrogen Leaching From Douglas-Fir Forests Following Urea Fertilization," and "The Use of Various Soil and Site Variables for Estimating Growth Response of Douglas-Fir to Multiple Applications of Urea and Determining Long-Term Effects on Soil Properties" (2008).

Alan A. Lucier

Alan A. Lucier is senior vice president of the National Council for Air and Stream Improvement, Inc. (NCASI) in Research Triangle Park, North Carolina. NCASI is a nonprofit environmental research organization serving the forest products industry since 1943. Dr. Lucier manages NCASI's forestry programs and overall research planning. He has worked in the forest products industry in research positions since 1981 and is co-founder, past chairman, and current board member of the Institute of Forest Biotechnology, and co-chair of the American Forest and Paper Association's Sustainable Forestry Task Group for Agenda 2020. In recent years, he has served on the expert panel on Forest Adaptation to Climate Change convened by the International Union of Forest Research Organizations, National Commission on Science for Sustainable Forestry, and Secretary of Agriculture's Forestry Research Advisory Committee.

Mike Schmidt

Mike Schmidt has been Manager, Forestry Renewables, for John Deere Construction & Forestry since 2006. As Forestry Renewables Manager, Mike is responsible for growing John Deere's forest biomass initiative, which includes identifying opportunities where John Deere's forestry products and services can provide solutions to rapidly evolving bioenergy industries. Mike has over 30 years' experience as a forester/manager in the forest products industry in the midwestern, southern, and western United States. He is a graduate of Oklahoma State University and currently makes his home in Davenport, IA.

James Rakestraw

James Rakestraw is director of forest research and technology for International Paper's worldwide operations. Prior to this, he was responsible for leading International Paper's domestic forest research and technology transfer programs in soils/silviculture, biometrics, forest economics/finance, forest health, genetics, and biotechnology. A primary focus of these programs was the productivity enhancement of softwood and hardwood plantations in the U.S. South. More recently, Dr. Rakestraw's activities have expanded to include forest technical issues in central Europe, South America, and Asia.

Robert Rummer

Robert Rummer has a Ph.D. in Industrial Engineering from Auburn University and is presently a project leader for the USDA Forest Service in Auburn, Alabama. He has authored or co-authored over 140 technical publications relating to forest operations. Dr. Rummer leads the Forest Operations Research Unit, which currently has a major emphasis on woody biomass harvesting and transport. His personal areas of study include alternative biomass transport systems, mechanical fuel reduction treatments, and harvest of woody biomass. Because of work in this area, Dr. Rummer serves on the Forest Products Lab Biomass Grant Review committee and is a member of the National Woody Biomass Utilization Group and the Interagency Feedstock Logistics Working Group of the Biomass R&D Board. He also provides technical consultation on the topic of woody biomass harvest and transport.

Timothy J. Tschaplinski

Timothy Tschaplinski has a Ph.D. in Forestry from the University of Toronto. He is a distinguished scientist for the Environmental Sciences Division at Oak Ridge National Laboratory (ORNL) in Tennessee. Prior to this he served as adjunct faculty at the UT-ORNL Genome Science & Technology Graduate School at the University of Tennessee. He has co-authored several publications, including "A Salicylate Hydroxylase Transgene in Poplar Induces Compensatory Mechanisms in the Shikimate and Phenylpropanoid Pathways," published in 2007 in *Phytochemistry*. For the 2006 DOE 30×30 Workshop on Biomass Energy, Dr. Tschaplinski was a member of the Wood Crop Development panel; in the same year, he was the lead of Woody Crop Development at the Southeast Regional Biomass Consortium. He has also served as coordinator of the Metabolic Characterization and Metabolomics section of the Science Plan for post-genome sequencing research.

Timothy Volk

Timothy Volk received his Ph.D. in Forest and Natural Resources Management from the State University of New York (SUNY) in 2002. He is presently working as a senior research associate for the SUNY College of Environmental Science and Forestry. He has co-authored several publications, the most recent of which is "Willow Biomass Production for Bioenergy, Biofuels and Bioproducts in New York" in the book Renewable Energy from Forest Resources in the United States (2009). In 2008, Dr. Volk was appointed as the Woody Feedstock Development team leader for the Northeast region of the U.S. to coordinate research and development efforts on woody biomass crops as part of the Sun Grant initiative, an effort that will focus on developing a network of collaborators and trials to determine woody biomass crop production potential in the region.

Ronald S. Zalesny, Jr.

Ronald Zalesny Jr. received his Ph.D. in Forest Biology from Iowa State University (ISU) in 2003. He is currently a research plant geneticist and team leader for the Genetics and Energy Crop Production Unit of the U.S. Forest Service, Institute for Applied Ecosystem Studies. Dr. Zalesny has authored or co-authored 125 publications, including peer-reviewed articles, proceedings, reports, and technical presentations. His synergistic activities include working as an adjunct professor for the ISU Department of Natural Resource Ecology and Management, serving on the Poplar Council of the United States, working as a member of the Steering Committee for the Short Rotation Woody Crops Operations Working Group, and serving on the editorial boards of BioEnergy Research and the International Journal of Phytoremediation.

Workshop Notes and References

1. Cost and availability of best planting stock.
2. Capacity to produce required number of plants.
3. The rapid scale up of new genetic material from the research level to commercial scale is currently limiting.
4. Availability of transgenics to improve yields.
5. Inability to use transgenesis to rapidly improve crop productivity.
6. Long generation time and lack of effective early selection tools.
7. Lack of ongoing and sustained support from government and industry to develop and sustain breeding programs. The turnaround from breeding to commercial deployment is 8 - 10 years for many of these woody crops. Short term funding and support makes the development of new material very challenging.
8. Type of planting stock in poplar - rooted versus unrooted. Costs associated with each relative to benefits.
9. Regeneration methods. (i.e., coppice, planting, natural)
10. Hardwood seedlings more expensive to grow and plant.
11. The wrong harvesting equipment can negatively impact yields.
12. Harvesting costs for biomass.
13. Need for new types of low impact harvesting and integrated harvesting equipment. Combine-like machines.
14. Cultural techniques, spacing, site prep, weed control, cultivation, fertilization, and pest.
15. Lack of efficient seed collection systems for eucalyptus.
16. Poorly understood cultural techniques means yields are greatly reduced by poor management.
17. Soil carbon and loss of soil fertility not well known.
18. Water quality impacts from heavy fertilization in the loblolly scenarios.
19. Choice of crops are limited in each region.
20. Site limitation factors (i.e., water, fertility, frost, soil organic matter and properties).
21. How do genotypes perform at specific sites and across regions?...Do genotypes perform as specialists (i.e., better at specific sites) or generalists (i.e., better across sites)?
22. Species site limitations (matching species to sites).
23. New insect and diseases that will reduce productivity - number of invasive pests is growing.
24. Need crops that have options for multiple markets.
25. Landowners want multiple crop options.
26. Integration of biomass production with other forest products production.
27. Forest management practices based on forest product specifications.
28. Risk of extrapolating pulpwood to biomass use.
29. For every million tons of wood use in the pulp industry approximately 350 permanent jobs are created. In contrast, for every million tons of wood use in the green biomass power industry approximately 25-35 permanent jobs are created. We do not need to create an uneven playing field with incentives that would favor energy over pulp as JOBS WILL BE LOST. Market factors without governmental intervention need to govern what happens in the pulp vs. green energy arena.
30. Landowners are hesitant to plant new crops that are not proven and where no stumpage price has been established on the front end.

31. Does fertilization show a positive response to justify the costs?
32. Variability and uncertainty in fertilizer costs in the future.
33. Increasing regulatory constraints on herbicide use.
34. Concerns that policy and regulatory decisions will restrict their access to markets.
35. Enhancing yield through molecular breeding.
36. Important to put a substantial emphasis on testing those families already developed to expedite release of new material.
37. Broaden number of species you do research on! Eucalyptus and possibly others.
38. Consider non native-invasive species such as Norway maple/Ailanthus which have naturally proven themselves to respond well to coppicing and site occupation. Challenge is it goes against the grain of current paradigm of eradicating them.
39. Varieties that are more efficient at using nutrients.
40. Freeze tolerance for fast growing trees.
41. Enhance nutrient use efficiency through transgenesis (e.g., DoF gene family).
42. Up-regulate transcription factors associated with drought tolerance and field test the resulting new transgenics.
43. This is a huge opportunity. This is a species that is a very fast growing tree and needs work to allow it to grow in cold climates. Need studies for invasiveness at the same time to dispel speculation about invasiveness.
44. Identify new candidate genes that regulate drought response networks that define tolerance, using drought-inducible promoters that are only active when drought is evident.
45. Performance of genotypes in management regimes that are less than optimal (which is what many landowners might employ).
46. Increase disease and pest resistance by inducing plant immunity through targeted identification and up-regulation of disease resistance networks.
47. Advanced generation pedigrees to identify QTL [quantitative trail loci] associated with traits of interest.
48. Identification of QTL associated traits of interest from large association studies, which generates candidate genes close to associated neutral markers, rather than one gene in a large QTL interval.
49. Value of transgenesis well.
50. Transgenic work to identify which genes are controlling crop yields.
51. Need research on GMO for pines and eucalyptus.
52. Further research on flower control for transgenics.
53. Research is needed to effectively limit inadvertent gene flow by generation of sterile plants when transgenesis has been employed.
54. Transgenics and other forms of high-yield biomass may not be “allowed” on the landscape (policy) without demonstrated control.
55. Since the mandate for green energy originates at the federal level, and thus creates demand for biomass resources, the feds need to support GMO work to increase biomass production as it is being vigorously challenged by environmental groups.
56. Better communication on issues important to the public.
57. Communication of realistic consequences of the use of cisgenic clones.

58. Look at end-product yield by species based on target market vs. dry matter yield. In other words, the highest dry matter yield may not give the highest end-product yield.

59. Typically we plant out genotypes that have previously been used without a detailed testing phase of how they will perform where we deploy them. One major limitation and its associated need is that of testing new genotypes so that selection of favorable clones can be effective for deployment.

60. Matching species based on soil pH, texture, depth.

61. Performance of genotypes in management regimes that are less than optimal (which is what many landowners might employ).

62. Poplar germplasm development has been a world-wide effort, but that effort has been fragmented and poorly organized. A coordinated effort to organize and screen material circulating through poplar "circles" seems a basic requirement to laying a good foundation for future advances.

63. The greatest potential for yield improvement for poplar is concerted breeding as well as development of base populations.

64. For poplar, capitalizing on heterosis based on species used as parents is very important. Basic research on incongruity issues is needed and can ultimately help to increase the probability of selecting favorable progeny.

65. Acceptance of the generation and field testing of cisgenic poplar clones are safe, because we are just upregulating native genes.

66. Genetic modification of poplars to provide drought tolerance

67. Need to develop plastic clones (poplar) which is indeed possible. Clone/Site matching will require a very intensive research effort. Based on our experience, stable (plastic) clones yield as high as other more site-sensitive clones.

68. Accelerate work on Pine Genome Initiative.

69. Improvement in vegetative propagation methods for pines and other tree species that are difficult to propagate.

70. Cold hardy eucalyptus.

71. Genetic modifications to eucalyptus to allow it to thrive in colder environments. This would allow for fast growing biomass trees to be developed to support the increased demand for biomass and wood.

72. More and larger trials with herbicides and fertilizers to maximize plant production.

73. This is one of multiple crop management issues that needs to be addressed and then revised as new genetic material is developed.

74. Will be very helpful for energy feedstock production (relative to traditional fiber applications).

75. Field trials have historically focused on traditional uses which require different spacing than those for energy. New spacing trials and other silvicultural requirements for energy purposes would be very helpful.

76. Combination of crop ideotype and spacing functions to improve trees per acre and maintain productivity.

77. The impact of plant density of these systems has impacts on other parts of the cropping systems like weed control, soil loss, nutrient management, and harvesting.

78. Piece size issues that affect harvesting costs that are affected by spacing.

79. Need to look at plant density relationships as new varieties are developed and how these patterns play into the type of end product that is produced.

80. Need to look at lower stocking levels which has reduction in early yield but creates fewer larger pieces that reduce harvest cost.

81. Coppice management of poplars has not been a high-priority item in the past decade due to the orientation of pulpwood and saw timber production. However, poplars are amenable to repeated coppice management. Yield curves under coppice management using new clones need to be developed.
82. Site specific, integrated management schemes.
83. Develop intercropping that provides fertilizer to the trees.
84. Intercropping with leguminous plants to increase more natural nitrogen capture and release to SRWCs.
85. Utilize some other species to capture growth potential in the early years of the SRWC when the stand is under stocked.
86. Nurse crop for hardwoods combining a high value saw log with an energy crop.
87. Understand max volume accumulation point for each species so as to capture most growth from the short rotation time frame.
88. Rotation length – growth curve.
89. Spacing element and interactions with harvesting capabilities to optimize planting strategy (rotation length, max growth return).
90. This is tied in and related with spacing issues - will vary by spacing and effect other aspects of crop management and needs to be looked at in an integrated fashion.
91. Longer rotations will reduce harvest costs per ton but will have other impacts on types of harvesting systems and supply to end user.
92. Look at optimal growth/ac/yr rate for all species planted.
93. Need process-driven growth projection models to replace empirical growth and yield models currently used.
94. Need research on how when and how it is used.
95. Understanding site requirements, particularly nitrogen is critical - response is variable, needs more fundamental research.
96. Add N fixation and other symbiotic relationships to crop trees
97. Need increased ability to conduct truly long-term studies on nutrient changes (i.e., multirotation).
98. Understanding balance between nutrient removals and movement, pools, availability, inputs and potential additions.
99. Nutrient use efficiency - currently only (at most) 25% of applied N gets into the tree.
100. Better understanding of fertilization responses. A proportion of poplar sites in the Upper Midwest don't show a commercially-significant growth response to fertilization. However, some do and site differences need to be better understood.
101. What site resources limit productivity - water, nutrients, soils.
102. This will be important for the use of marginal land. Very little work has been done on nutrient management on marginal land with woody crops.
103. Understanding impacts of nutrient removals on marginal lands.
104. Understanding of relationships between nutrient additions, where they go, other impacts on the ecosystem, effect on competing plants (pests and weeds), and loss mechanisms for the nutrients added.
105. Research on ash from boilers etc. to be applied to the land as fertilizer. Look at costs of the system.
106. Application of conversion waste (ash) to SRWC regime.
107. Integrated use of biosolids and residuals as a supply of nutrients.

108. Phytotechnologies are being used to incorporate waste management with intensive forestry while using wastewaters as fertilization and irrigation for the trees. This can help sustain the environment and costs, as well as increasing yield.

109. Invasive pests.

110. This is going to be critical over time. As Don Dickman often says - if you plant them they will come. Monitoring of pests and diseases needs to be integrated into the development of new genetic material and during crop management techniques.

111. Monocultures will require very careful and continual protection systems for pests and disease outbreaks.

112. Better ways to monitor for pests and diseases.

113. Technology development for real-time monitoring of nutrient condition for better timing/rate of application.

114. Technology to apply the optimal nutrition, growing conditions at very site-specific scales.

115. This can be very powerful, especially if clones are matched to areas within the field and the optimal nutrition, etc. in #32.

116. Low cost methods (e.g., remote sensing) to quantify growth rate, standing inventory.

117. Need to push monitoring/sensing basic research for biomass properties and plant responses to support precision applications.

118. Root dips at time of planting/oversprays. SC-27 produced by Martin Marietta materials. Helps reduce fertilizer inputs/need.

119. Technological advances in nursery production to reduce seedling cost of advanced planting stock.

120. Need advancements to clean and efficiently handle eucalyptus seed and work on cloning eucalyptus. Need to develop seed orchards for fast growing trees. Scale up is very slow if breakthroughs are made in cold tolerance in eucalyptus.

121. This should include harvesting systems to optimize costs, minimize harvesting losses, and minimize impact on the site and the next coppice rotation.

122. Need for new types of low impact harvesting and integrated harvesting equipment. Combine-like machines.

123. Need whole tree extraction systems to capture volume in stumps. 21% more volume in the pine stumps.

124. Need research on equipment to harvest the entire tree, including the stump.

125. Research to understand competition effects and control strategies.

126. Also understand effects of spacing, thinning, etc., on competition within species.

127. It is important to consider both aboveground and belowground competition and their impacts on yield.

128. Understanding what level of weed competition is really impacting a woody crop is not well understood so that the right amount of management is applied.

129. Better understanding of weed impacts that become a limiting factor.

130. Lack of labeling of herbicides has the potential to be a real barrier to future development of woody crops.

131. Better labels on herbicides

132. Need more flexibility to use herbicides that are not labeled for the application if it works without going through the lengthy labeling process since it is not used for food crops.

133. Consider both nutrient cycling and additions of carbon to belowground pools.

134. Knowing the nutrient removal impacts of taking off additional biomass (i.e., foliage, branches, roots) in comparison to traditional bole, etc.

135. Optimize competition management strategy.

136. 21% more volume from pines are underground. The challenge is cost effective methods to harvest. Time to replant is reduced. Will need to harrow or bed before planting. productivity improvement will cover the costs of needed fertilization.

137. European technology exists for stump extraction but the cost of re-establishing a crop site might make it prohibitive.

138. Integrated harvesting/site prep operation (stump removal as part of harvest but also as first step in site prep) could improve efficiency and reduce impacts.

139. Development of conversion technology ability to use more of the biomass production--OK to use bark, foliage, less sensitive to dirt, etc.

140. Total utilization brings with it issues of biomass contamination (dirt, rocks, etc.) which will drive harvesting equipment modifications.

141. Multiple products streams and potential to feed the residual materials back to the site, i.e., pyrolitic reduction of biomass and residual of biochar to further improve and enhance growing sites, nutrient retention.

142. There are opportunities to use residuals, biosolids, fly ash, as nutrient sources. There may be a way to develop integrated regimes that recycle materials to provide nutrients needed to increase productivity and maintain soil quality. Reuse and recycle as part of this system.

143. Need to think about the yield from woody crops in terms of items other than tons of wood. There are high value compounds that can be extracted from wood that will make a ton of biomass a high value product.

144. We need systems that provide landowners other revenue streams from the acre of land beyond the low value biomass species. Agri-forestry, intercropping, Flex Stand.

145. A huge opportunity exists to use genetic engineering to enhance the production of valuable co-products. Genes are being identified that regulate the production of such metabolites.

146. Research needed to better characterize the metabolites that exist in different tissues of various woody crops and specific clones.

147. Age of woody biomass impacts products that can be extracted.

148. Need to identify costs of merchandizing multiple products from these systems.

149. Encouragement of coop members to push the envelope.

150. Education from K-graduate level that forestry is not synonymous with destruction of nature, in fact, production forests offer many environmental benefits over alternative uses.

151. Genetic breeding may help to expedite release of clones, as much as possible.

152. Very little discussion has occurred regarding the needs of the molecular genetics community with the applied breeding programs. Large scale breeding programs to develop commercial clones may or may not meet the needs of the molecular genetics community (family structure requirements, clones within families). Also, the reality that large scale genetics tests are short term by their very nature. Fast growing clones express themselves early and the study rapidly become irrelevant (or at least suspect).

153. Long-term support of breeding, genotypic screening, clonal trials, and yield trials.

154. This is important because these are biological systems and need to be looked at holistically - nutrient management, spacing, rotation length, pest and disease management, soil loss, weed management etc. Looking at these issues separately often ends up with the result that some other part of the crop management system had the greatest impact. Integrated work would help to address these issues.

155. Long-term means 7-8 years.

156. Balanced research portfolio with applied (short term) and basic (longer-term) work that includes genetics, silviculture, harvesting, etc.

157. Regionally distributed to be applicable.

158. Long-term (over multi-rotations) large scale, multi-site true yield trial,
159. Yield trials to full rotation depending on region and over large area (e.g., 1000 ac per advanced generation poplar clone). True yield trial and not just short-term spacing and fertilizer trial.
160. Region wide yield trials that examine potential growth of species.
161. Need to have regional species comparison trials to get a base view of how primary SRWC's perform on a variety of sites. Assumption is that these species will do well everywhere.
162. Need to cover range of soils and climate conditions.
163. Systems for making informed decisions on where to test/deploy genotypes in areas where they have not been previously grown are needed and can help to increase plantations success and ultimate yield.
164. True yield blocking trials are a must in order to test the productivity of clones without competition from other genotypes.
165. A serious need to developing yield models based on good long term yield trials so that the estimates across the landscape can be more accurate. This is important for both national studies, but also for project specific projects. At this point we are making broad estimates across large land areas.
166. Owners have other motivations than high risk income such as family history in land use.
167. Landowner motivations vary depending on whether they are active farmers or people who own agricultural land but don't personally manage it.
168. Farmers may not like trees.
169. Ag landowners are not familiar/comfortable with tree culture/mgmt.
170. Longer short-rotation may be more popular for some landowners.
171. Current forestland owners may be more likely to opt for pine SRWC (12 yr) rather than hdwd (3 yr) because it is more like a forest.
172. SRWC may not provide any other intrinsic values to a land owner such as wildlife. Too much of a monoculture compared to forest land. Must view this as a perennial Ag crop.
173. Forestland owners returns values of wildlife, etc that are not obtainable from SRWC culture.
174. Must prove out the compatibility of SRWCs to Landowners objectives.
175. Questions and conflicting objectives in the protection of biodiversity, water quality, and soil conservation….
176. Lack of understanding of the biodiversity benefits of srwc is a barrier to deployment.
177. Misperception that woody crops can be grown like conifers planted in old fields.
178. Perception the we will convert forest land to short-rotation woody crops.
179. Major barrier in Lake States given the public's view that we will lose forestland to these crops - even though we have never proposed this shift.
180. Knowledge and education of landowner on options and what it really means.
181. Financial ability of landowner to make investment.
182. Landowners make decisions based on best economic return and they will make changes on land use based on that.
183. High upfront costs for establishing woody energy crops and delay to first harvest and return on initial investment.
184. High upfront costs and length of time until an economic return is realized are barriers to landowners planting trees.
185. Too long term of an investment.

186. Since woody crops need longer rotations and landowners do not project the future very well, they are hesitant to invest.

187. Since much of the lands are owned by small landowners short term returns will incent them to plant.

188. Long-term contracts with end-users will guarantee acceptable ROIs and reduce risk.

189. Long-term contracts referenced to cost indexes are not mainstream, which will raise risk for landowners.

190. Not simply NPV, it also has to address cash flow objectives/capability of private landowners.

191. Limited local markets to drive demand.

192. Local market for biomass based on proximity to a biomass energy facility.

193. Inability to predict.

194. Uncertain future for markets causes landowners to hesitate to invest or agree to engage in producing a long term crop.

195. Uncertain consumers of biomass right now restricts many land owners from planting a dedicated biomass crop. They are looking for multiple use cropping systems.

196. Farmers are notorious for finding the best ways to make money from their land. Switching crops depending on expected markets is common. Create a place to take it and a financially attractive price and they will come.

197. Financial returns will determine this...if the returns are great enough landowners will do it.

198. Stable biomass markets will motivate landowners.

199. Perception that energy crops do not have a high value added.

200. Low financial returns to the land owner.

201. Farmers are notorious for finding the best ways to make money from their land. Switching crops depending on expected markets is common. Create a place to take it and a financially attractive price and they will come.

202. Financial returns will determine this...if the returns are great enough landowners will do it.

203. Economics for biomass does not compare to growing pine saw timber.

204. Relative prices of livestock and pulpwood will be key factor affecting feasibility of growing SRWC on pasture land.

205. Really need some major yield improvements to make economics favorable.

206. No definition on what the yield function looks like.

207. Different than with Ag crops.

208. Uncertainty about yields for short rotation crops is a problem for land owner adoption.

209. Operating costs are significantly impacted by parcel size (higher for smaller landowners).

210. Small parcels may not have scale necessary for practical application of technology.

211. Increased Transportation distances.

212. Depending on end use, this could be offset with modular facilities.

213. Bio regional biorefineries.

214. Location of biomass facilities nearby reduces costs and raises prices paid for biomass. Aggregation of sources (i.e., PNW national forests produce few wood products currently) can result in a higher density of use facilities and lower transportation costs.

215. Need to develop alternative types of biomass facilities from the present mass burn mentality….

216. Uncertainty with regard to incentive programs—5-year extension on CRP was enough for trees.

217. Ag trade policy and definition of renewable biomass.

218. This topic (and tax policy) overwhelm all others.

219. Tax reform is a key to sustainable forestry and expansion of woody biomass supplies.

220. Cost depletion schedules would need adjusting to make longer-term capital investments more competitive with Ag alternatives.

221. REITs and TIMOs drive ownership and reduce integration of products sources and utilization.

222. Expected yield by LCC is not well understood. The potential exists for relatively high yields on poorer quality land.

223. Ag landowners are used to crop management, more likely to move marginal Ag land into SRWC--not just pastureland.

224. Non farmers may want higher quality land in SRWC.

225. Forest lands will be converted to short rotation crops like eucalyptus. It is all a matter of economics.

226. Lower MS alluvial valley should show up as potential hardwood SRWC area--reality check for predictions.

227. BT2 is missing lots of land area as potential--woodlands in the western US for example. Poplar in E Oregon wouldn't have been predicted under base assumptions.

228. What about power and gas ROW's for growing a relatively short in height crop that is harvested frequently.

229. Must demonstrate sustainability of various land-use to address national public policy debate over land-use change.

230. Demonstrate the wildlife value of ephemeral habitat cover/change for wildlife diversity, i.e., shrub land avian species/shrub lands are the most at risk or least cover type...does willow SRWC meet this test top provide such habitat?

231. Determination of fertilizer response (nitrogen in particular) and long-term water quality comparisons among various cropping systems (pasture, corn, woody crop).

232. It is unlikely that public land will be used for this.

233. Public lands should be eliminated from forest availability numbers unless the feds & state agencies change public policy on public lands to make the wood available to support the green energy demand.

234. Until public lands are protected from frivolous/extremist litigation they are off the table.

235. Public land managers need to have clear priorities and production of commodities needs to be one of them.

236. At least site prep costs should be considered as qualifying for tax treatment as expenses rather than capital investments that must be recovered over a longer depletion schedule.

237. Allow currently capitalized costs to be expensed for tax purposes.

238. Follow soil bank, CRP, and other successful tree planting programs from the past.

239. Biomass Crop Assistance Program is a model for this on a limited basis (pays 75% of planting in BCAP zones).

240. 100% tax credit for site prep costs and planting of crops will have immediate return! Site prep contractors will be at work immediately, nurseries will be planting trees because they have orders for trees, biomass will be planted. There is little paper work for the government… just tax returns… no USDA staff requirements. Must provide receipts for expenses.

241. Definitions of what biomass is need to be clear and reasonable.

242. Carbon capture storage annual revenue stream.

243. If woody materials are pyrolized to produce liquid fuel the residual is biochar, and should qualify as permanently fixed carbon. SRWC as carbon scrubbers.

244. Can you claim carbon capture credit for short rotations going to energy? Not sure it applies for landowner.

245. Recognize that forest sector is by far the largest current producer of bioenergy.

246. Align tax and environmental policies with national objective to increase competitiveness of U.S. forest sector in global markets for pulp, building products, and biofuels/new biomaerials.

247. Recognize opportunities to expand combined heat and power production with biomass at U.S. pulp and paper mills.

248. More frequent recovery of crop (compared to forestland) makes the SRWC business model more attractive.

249. Longer short-rotation species may be more appealing for certain land owners, and others may like the option to put back into in shorter rotation (3 year) if they didn't like how things were going.

250. Shared risk of the producer with the energy generator.

251. Biomass facilities work with landowners to cover establishment and management costs and provide an annual revenue and a guaranteed market.

252. Risk needs to be shared between landowners and end users - possibly government as well.

253. Land leased by biomass users.

254. Use the model that chicken farmers use with large poultry companies, the Purdue Chicken farmer model.

255. SRWC may have long-term stable contracts (with biomass users).

256. Long-term contracts which look like an annuity create a predictable cash flow for landowners.

257. The farmer will want to see the take away. the chicken farm model works because there is a demand for chickens and a company committed to buy them.

258. Pulp and paper companies in South America who use eucalyptus have a business model where they work with local landowners to provide seedlings, technology, annual payments, and a market for the final product.

259. This business model also works for the seedling provider in a three-way agreement.

260. Other business models communicated to the land owners.

261. Create educational material on different business models.

262. Landowners need to really understand what is involved with this type of cropping and harvesting.

263. Educate biomass facilities that they have to develop a business model that recognizes the needs of the landowners for annual payments and a confirmed market.

264. This idea is currently being expanded upon by developing a GIS-based spatial analysis protocol to identify candidate core areas where SRWC can be tested/deployed, then evaluating soil health, water quality, carbon, and other parameters within those areas. In addition, productivity is being evaluated within these areas.

265. Once idle acres are identified, those landowners need to be encouraged to plant biomass crops.

266. Need to then take the remote sensing a step further and engage the landowners. Social aspects of developing this supply are often not addressed. They are confusing and somewhat messy, but essential to developing these systems.

267. Landowners will need to be incentivized or contracted to establish and plant SRWCs.

268. Site preparation practices need to be developed and refined to address concerns with soil erosion potential.

269. Continue trend of replacing mechanical site prep with chemical site prep (where feasible) to reduce soil. erosion potential.

270. Stand density effects on wildlife habitat - high-density coppice versus wider pulpwood rotations.

271. Selecting varieties, genotypes that are efficient users of nitrogen.

272. Enhance nutrient-use efficiency through transgenesis.

273. Enhance water-use efficiency and drought tolerance via transgenesis.
274. Focus on GMO modifications to eucs so the range can be expanded.
275. GMOs could provide solutions for remediation practices.
276. Modifying native genes versus introduction of transgenes where possible.
277. Ensure lack of gene escape via co-introduction of sterility.
278. Minimizing energy inputs through more efficient operations.
279. Move to whole tree harvesting systems to get the tops and roots in one pass.
280. New technology for operations (harvesting, site prep) that minimize effects like erosion, soil properties.
281. Harvesting systems that protect soil properties (compaction, rutting, etc.).
282. Systems which deliver reduced depletion of soil organics, i.e., 30% of organics left during harvest.
283. Debarking and redistribution of bark on-site to reduce nitrogen removal in poplar and willow.
284. Harvest SRWC in dormant season to leave most of the nutrients on site in the foliage. Leave stems on sites that are harvested during the growing season to have foliage left on site.
285. Intercropping can provide multiple ecosystem values compared to monoculture regimes.
286. Interplanting short rotation woody crops with species like triticale can increase sustainability across the landscape.
287. Plant SRWC's in cropland corners.
288. Increase yields through biotech and precision forestry methods on soils well suited for intensive management.
289. Reintroduce trees into appropriate landscapes in Ag areas.
290. Short rotation woody crops may still be better for environment that agronomic crops on land with erosion potential.
291. Creating integrated landscapes by introducing SRWC into key locations to address concerns with livestock and crop production.
292. More integration of systems.
293. Woody crops may provide a crop rotation option that improves the productivity of the land.
294. SRWC can be the most sustainable across the landscape provided they are strategically placed to recycle nutrients and to maintain genetic diversity relative to previous systems (i.e., pasture, hay, etc.).
295. Use all public corridors for SRWC. Power lines, road dividers, shoulders. They could stop mowing and use the land for a productive use for the entire country.
296. Use of public right-of-ways.
297. Ability to create corridors and connect fragmented landscapes.
298. Longer rotations in streamside management zones.
299. Research designs that incorporate the entire system. Use wastewater from pulp mills to irrigate energy crops. Use the ash from boilers to spread on lands as fertilizer to grow energy crops and other plantations.
300. Common wastewaters used to incorporate waste management with intensive forestry include landfill leachates, paper mill sludge effluents, septage effluents, etc.
301. Source of nutrients and organic matter to increase productivity and maintain soil quality.
302. Replacing commercially produced N fertilizer with biosolids can replace the net energy balance of the system by 50% and reduce GHG dramatically.
303. Alternative waste disposal costs for mill and municipal biosolids can pay application costs.

304. Keeps biosolids out of food supply (which occurs when they are used in agronomic systems).
305. Will likely need to be subsidized by the cost of waste disposal as the value of the added nutrition will not pay for transportation and application.
306. Use stumps as biomass for energy. Stumps were used in the past and some now for biproducts (i.e. Turpentine etc.) and people did not raise concerns, yet people raise concerns now. The fact is any nutrients that are removed for any crop will eventually have to be replaced.
307. All tree tops should be skidded to the ramps and topped there so they can be ground or chipped and used for fuel.
308. Harvest window for short-rotation woody crops is short. Residue management will require the ability to handle a surge of residues.
309. Harvest window is actually long compared to Ag energy crops, depending on.
310. Developing technology to estimate residue retention requirements rather than blanket guideline quantities.
311. Some percentage of residue needs to be retained on the site, i.e., not less than 20%.
312. Emphasizing scattering of harvest residues when they are concentrated on landings in low nutrient sites.
313. Best management practices.
314. Monitoring and response for adverse changes.
315. Minimizing application of fertilizer, pesticide, herbicide through Precision Forestry.
316. Develop herbicides and rates to minimize application rates and maximize weed control.
317. Need to tailor BMPs for the SRWC system and the region of the harvest.
318. Developing site preparation systems to minimize erosion potential and nutrient loss by developing reduced tillage practices and cover cropping systems.
319. Operations that minimize soil movement, tillage requirements, disturbance.
320. Changing systems to reduce runoff (lessons learned from Brazil).
321. Managing water (i.e., terracing) to increase water availability to trees.
322. Eliminating physical limitations (i.e., pans) in soils.
323. Definition of biomass harvesting guidelines in Federal and State policy have to address SRWC differently than biomass from natural stands.
324. Excessive/random BMPs have the potential to increase costs beyond sustainability and profitability.
325. Soil properties including carbon and nutrient cycling.
326. Using N fixing and deep rooted cycling species.
327. Research to determine carbon sequestration in woody crops.
328. Better define the potential of below ground C storage in SRWC. There is very little known about this and in order to improve it we need to understand the baseline that we have now.
329. This is very difficult, especially for belowground tissues, but is being actively pursued in the Lake States as part of the development of a regional model for carbon sequestration of SRWC.
330. Operations that broadly improve site productivity through tillage practices or soil amendment.
331. Education of public to understand the values of SRWC and address sustainability concerns.
332. Need to work on public perceptions of what is "sustainable" and how SRWC complies.
333. Woody species should be easier to inventory.

334. Site by site plans to develop these sites to address both contamination concerns and produce biomass for renewable energy.

335. Large swaths of Mtn Top removal coal reclamation would lend themselves to SRWC if appropriate species can be identified.

336. Short rotation woody crops in reclamation of strip mines where coal what mined.

337. This includes all phytotechnologies. Current efforts with poplar and willow involve matching clones with specific contaminants and where those contaminants are stored in the tissues.

338. Biorefining of the material yielded from these sites would require special processing to extract the toxins absorbed for proper disposal/encapsulation.

339. We need to use a systems approach to advance yield and minimize costs. Looking at pieces in isolation will often miss opportunities for some synergy.

340. Development of cost efficient planting stock production systems.

341. Mechanization of planting stock preparation and handling.

342. Improved mechanized planting systems.

343. Develop harvesting systems that can be sued across a wide range of both agricultural and SRWC systems to maximize the acres covered and tons produced by a single unit - spread the capital costs across more tons of material.

344. Improve recovery efficiency of harvesting, processing and transport to minimize losses.

345. Develop in-field processing operations to improve feedstock--drying, chipping.

346. Develop harvesting systems that can work during a wider range of conditions (wet, winter, etc.).

347. Harvesting systems that can be used across a range of crops and systems.

348. One pass systems that cut, strip, chip and dispense a la combines....big powerful machines running on Biodiesel!

349. Continuous travel felling equipment.

350. Tracked systems.

351. Develop systems that minimize energy input per ton produced (fuel efficiency).

352. Largely depends on end uses.

353. Understanding the relationship between site quality and yield.

354. Optimal rotations to minimize soil compaction and nutrient depletion. What is optimal?

355. Matching site quality and plants for optimal rotation length.

356. Understand the impact of different spacing of plants on PAI of crops.

357. What is the value of storing biomass on the stump?

358. New role of Ag Extension with emphasis to aid landowners growing crops.

359. Understand fertilization response by site to maximize impact of fertilizer application.

360. Optimize yield, not maximize yield.

361. Overcome or address management costs for inputs required to increase yield.

362. Transgenic herbicide-resistant trees can allow the more effective use of herbicides and cheaper herbicides.

363. Using waste streams (organic amendments) rather than commercially produced fertilizer.

364. Utilization of wastewaters and other potential fertilization methods that reduce environmental and economic costs relative to traditional methods.

365. Most water treatments facilities that produce biosolids need a place to dispose of them and will provide them to the landowners for free ....this provides a source of nutrients needed to increase growth rates at a low cost to landowner that might make the economics of short rotation crops viable.

366. Genetic improvement is critical - need robust, high-yielding clones with demonstrated performance – our research in Minnesota demonstrates very high potential for yield improvement – 1.5 to 1.8 times that of the current commercial poplar clone – NM6, However, a national breeding and field testing effort is absolutely necessary in order to capture this potential.

367. Improved yield through effective selection of favorable genetic material from field testing.

368. Employ gene stacking to introduce multiple candidate genes enhancing productivity traits into already high productivity clones.

369. Enhance drought tolerance.

370. Enhance pest and disease resistance through transgenesis.

371. Improved yields through transgenics.

372. Develop species that can be harvested during a wider time period without adversely impacting regeneration.

373. Shared risk by landowners and end users.

374. Up-front lease payments for landowners along the lines of oil and gas leasing.

375. Long-term annuity like contracts referenced to cost/price indexes.

376. Structured payments based on long-term agreements indexed to markets, costs, etc.

377. Guaranteed payments to landowners.

378. Annual payments to landowner for future crop to be delivered.

379. CCS payments could increase incentivization.

380. Harvest SRWC when the markets, volume, and marginal gain is maximum not at some fixed rotation.

381. Producing multiple products from each ton of biomass to increase the value to both the landowner and end user.

382. For SRWC can we apportion the wood to a variety of values that make the economics look better.

383. Develop crops with lower final water content at harvest.

384. Moisture and density are the two items that affect transportation the most.

385. Development of in-field processing systems to reduce transportation costs.

386. Storage solutions.

387. Ability to store woody biomass will reduce market price fluctuation risks.

388. Integrate biomass supply from different sources over the year to reduce storage costs.

389. Bundling systems to facilitate drying and long-term storage - increase energy yield.

390. Major limitation of fertilization in PNW is uncertainty, partly in prices, but all the way up to being able to cut forests in the future because of regulation.

391. Align tax, trade and environmental policies with national goal to increase competitiveness of US forest sector in global markets for wood, pulp, building products, biofuels and biomaterials.

392. Government support for the initial deployment of SRWC to kick start the industry - BCAP with enough $ and years of support to build a base industry.