Safety and Health in On-Farm Biomass Production and Processing

D. H. Schaufler, A. M. Yoder, D. J. Murphy, C. V. Schwab, A. F. Dehart

Abstract. *There is significant interest in biomass production ranging from government agencies to the private sector, both inside and outside of the traditional production agricultural setting. This interest has led to an increase in the development and production of biomass crops. Much of this effort has focused on specific segments of the process, and more specifically on the mechanics of these individual segments. From a review of the scientific literature, it is seen that little effort has been put into identifying, classifying, and preventing safety hazards in on-farm biomass production systems. This article describes the current status of the knowledge pertaining to health and safety factors of biomass production and storage in the U.S. and identifies areas of standards development that the biomass industry needs from the agricultural safety and health community.*

Keywords. *Biomass, Haddon matrix, Health, Hazard, Production, Risk, Safety, Storage, Terminology.*

In 2005, the U.S. Congress established the Biomass R&D Technical Advisory Committee, which envisioned a goal of replacing 30% of U.S. petroleum consumption with biofuels by 2030, as described by Perlack et al. (2005). The U.S. Department of Energy and the USDA partnered to complete a study on the technical feasibility of producing one billion tons of biomass feedstock each year, known as the One-Billion Ton study. This 2005 study found that it was feasible to produce 1.3 billion tons of feedstock from forestland and agricultural land annually without compromising food, feed, or export demands. As a result, significant research is in progress by public universities, national laboratories, businesses, and other entities on many aspects of the biomass industry. An update of the One-Billion Ton study was completed in August 2011 that confirmed the predictions of the 2005 study, while providing more specific estimates of production by the mid-21st century (U.S. DOE, 2011).

Biomass includes organic materials that are plant or animal-based, such as dedicated energy crops, agricultural crops, forest products, and food, feed, and fiber crop residues, as detailed in ASABE Standard S593.1 (ASABE, 2011). In 2011, the U.S. obtained 4.5%

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of its total energy from biomass, according to the U.S. Energy Information Administration (U.S. EIA, 2013). This represented a 47% increase in biomass energy production since 2000. About half of current U.S. biomass consumption comes from forest and crop residues and half from fuel ethanol. As of 2011, biomass crops accounted for 49% of renewable energy produced in the U.S.

Energy crops grown and processed in the U.S. can be categorized into woody biomass, crop residues, and grasses. Woody biomass can be residue harvested following or as part of a logging operation or woody materials planted specifically for energy production. Crop residues are recovered either during or following agricultural commodity crop harvest. Dedicated energy crops are planted and harvested specifically for the biomass. Biomass is left loose, chopped, pelleted, or baled to ease transportation, processing, and combustion, as described by Williams et al. (2008). While there is potential for many crops to be used for biomass production, there are several dedicated energy crops in the northeastern U.S. that provide "maximum potential for the region's widespread abandoned and marginal lands" (NEWBio, 2013).

The Northeast Woody/Warm-season Biomass Consortium (NEWBio) focuses on three perennial energy crops that are well-suited to the environment in the northeastern U.S. These crops are willow (*Salix* sp.), switchgrass (*Panicum virgatum*), and miscanthus (*Miscanthus* × *giganteus*). Willow is a short-rotation woody crop, while switchgrass and miscanthus are warm-season perennial grasses, as described in the NEWBio literature (NEWBio, 2013).

A significant benefit of using willow, switchgrass, and miscanthus is that these crops grow productively on marginal land. Marginal land is land that has limitations for sustained application for crop production. Even when increased inputs are used, minimal benefits are generally seen with food crops on marginal land (FAO, 1999). Marginal land is readily available in the northeast region of the U.S., with over 2.8 million ha of unused low-cost agricultural land and 0.5 million ha of recovered mine land available, according to the NEWBio Project Proposal (NEWBio, 2011). Marginal land cannot sustainably support conventional commodity crops, but it may be suited to the production of dedicated energy crops.

Figure 1 illustrates the NEWBio partner institutions (stars), regional demonstration sites (circles), and approximate locations of idle lands (brown), croplands that could become available due to increases in crop yield (green), and mining lands (red). Each dot represents 2,000 acres, according to the NEWBio Project Proposal (NEWBio, 2011).

A systematic review of national and international literature regarding biomass systems has been conducted to identify processes where hazards could be present. This hazard identification is for on-farm biomass production, storage, and transport of these biomass crops. On-farm production may include some processing steps to densify the crop, but large, industrial-scale systems are not considered in this article. Biomass systems growing willow, switchgrass, and miscanthus and similar woody and warm-season grass crops were reviewed. The stages of field preparation, planting, crop maintenance, harvest, transport, processing, and storage were examined. Using information from the biomass industry and other agricultural industries with similar processes and equipment, a list of possible health and safety hazards was compiled.

Many marginal lands are typical croplands that have relatively low or negative commodity crop profitability because of poor soils, drainage, or other factors. These marginal

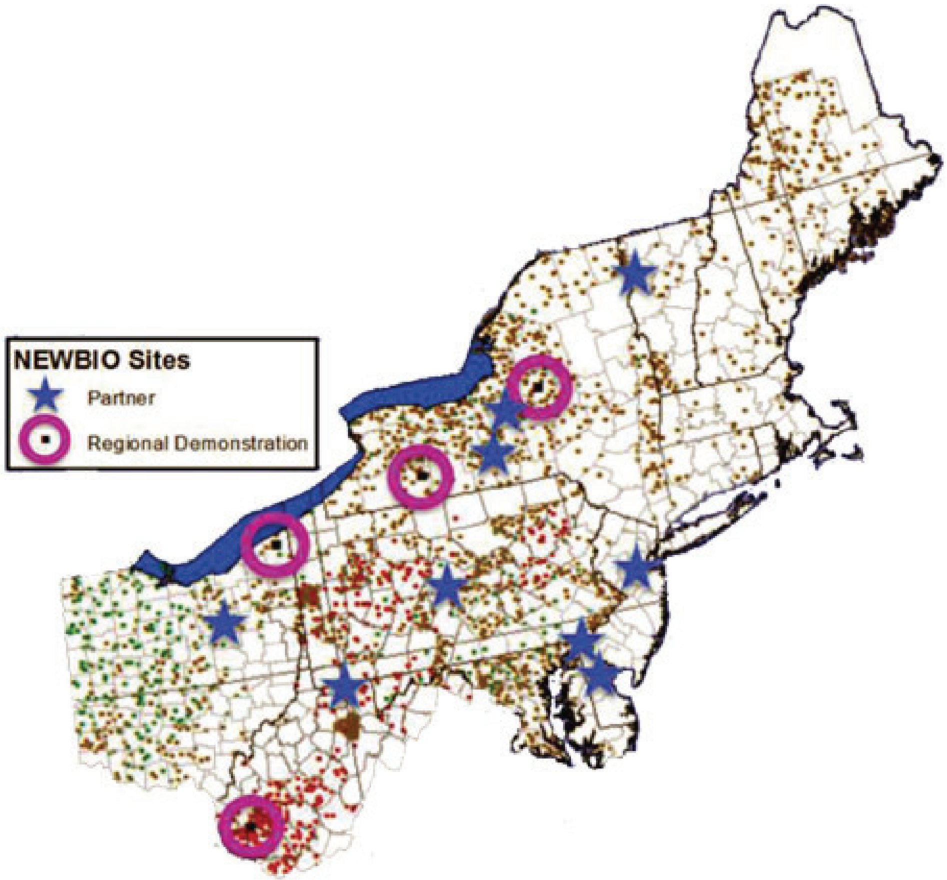


Figure 1. NEWBio project information.

lands may not have severe topography but are marginal because of soil conditions. Other lands are marginal because of topography, proximity to waterways, presence of rock outcroppings, and other production hazards. The use of some marginal lands for crop production presents several difficulties from an agricultural safety perspective. Depending on the location of the land, these may include planting and harvesting on slopes, or operating equipment in less than ideal weather conditions, including frozen snow-covered ground and wet or muddy fields. In addition, because of the marginal condition of the land, operators must be vigilant to avoid rocks and other hazards in the fields.

Biomass Production Systems

It is important to understand the processes and equipment involved in biomass production to identify the potential safety and health hazards associated with the production of willow, switchgrass, and miscanthus crops, as well as other biomass crops. The production process from field preparation to storage was examined for each crop, and the equipment used was identified. The information gathered was then compiled in table 1. This table subdivides the biomass production system into four categories. Each of these categories represents a specific stage of biomass production and includes a unique set of equipment used in that process. It is important to note that while each production segment uses different equipment, all stages involve transporting equipment on public roads as well as in the fields.

Table 1 identifies the most common equipment used in biomass production for the three crops in this study. This is not a comprehensive table, as similar equipment could be substituted for equipment listed in the table. However, the equipment used for these processes will be similar and will present similar safety hazards and injury incident potential. All three crops include the option of either baling the biomass material or chopping/chipping the crop during or following harvest. Based on observations, switchgrass and miscanthus are most commonly baled, while willow is generally chipped during harvest using a modified forage harvester or a machine custom-built for this purpose.

In table 1, the equipment used is arranged by process and crop. Each column represents a crop, followed by a list of the equipment used for production and processing of that crop. Many of the same types of equipment are used for various crops. For example, tractors are used in various stages for all three crops. More specialized types of equipment, such as the modified forage harvesters used for short-rotation woody crops, may only be used in one type of crop.

There are some processes that have machines unique to biomass operations. Most of the unique machines are associated with short-rotation woody crops like willow. These

Table 1. Typical equipment used in biomass production systems.

	Crop Type		
Process	Switchgrass	Miscanthus	Willow
Field preparation and crop establishment	Bulldozer[a] Tractor Tillage equipment Sprayer Seed drill Broadcast spreader	Bulldozer[a] Tractor Tillage equipment Sprayer Rhizome planter Modified potato planter	Bulldozer[a] Tractor Tillage equipment Sprayer Shoot planter
Crop maintenance	Tractor Sprayer Broadcast spreader	Tractor Sprayer Broadcast spreader	Tractor Sprayer Broadcast spreader Rotary/sickle bar mower
Harvest and in-field processing	Tractor Mower Hay rake Hay baler Forage harvester Wagon Truck	Tractor Mower Hay rake Hay baler Forage harvester Wagon Truck	Tractor Biomass baler Modified forage harvester Chipping harvester Wagon Truck
Biomass transport and storage	Tractor Wagon Material handling equipment Truck Bin Building Bunker/pile	Tractor Wagon Material handling equipment Truck Bin Building Bunker/pile	Tractor Wagon Material handling equipment Truck Bin Building Bunker/pile

[a] Used for initial land reclamation.

woody crops fall between a typical agricultural crop and a forestry crop. Small shoots are planted to start the plantation, and the crop is harvested after three or four years of growth, when the woody stem is larger than a typical annual agricultural crop. The planting and harvesting equipment is therefore unique for these woody crops.

All of the various processes involving different equipment present unique hazards. Many of these processes are similar to those used in many other production agriculture operations in the U.S., and the hazards associated with the use of this equipment have been studied. However, the use of this equipment in on-farm biomass production involves several issues that could create the opportunity for increased or different injury incidents. Additionally, other hazards may be unique or increased in prevalence for on-farm biomass production systems, as noted below.

Presented below are potential hazards that may be unique or more prevalent to on-farm biomass production systems (Gunderson, 2013). While these hazards exist for other farm activities, they may become more widespread because of the volume of biomass produced.

Fire hazards:
- Crops are harvested when very dry, producing fine, dry dust.
- Large areas of dry, standing crop before and during harvest.
- Storage of harvested crops that are not at proper moisture content for storage.
- Large piles of dry stored materials.

Respiratory hazards:
- Crops are harvested when very dry, producing fine, dry dust.
- Stored material may harbor molds and fungus.
- Stored material may harbor rodents or other animals that produce fecal material.
- Nuisance dusts such as soil and fiber material.

Machinery hazards:
- Thrown objects from aggressive harvesting machinery used on woody biomass.
- Aggressive cutting edges and speeds on harvesting machinery.
- Slipping on equipment ladders and steps during wet or snowy weather.
- Machinery sliding because of use on wet or snowy fields.
- Large or oversized equipment traveling on roadways.
- Large amounts of heavy material are handled during storage and transportation.

Marginal land hazards:
- Sliding or overturns when operating on steep slopes.
- Overturns from operating too close to waterways, ditches, or rock outcroppings.
- Retrieval of heavy equipment stuck because of wet or slippery conditions.

Biomass Production Injuries Literature Search

Once a basic level of understanding of on-farm biomass production was achieved, a literature search of both international and domestic literature was conducted.

International Literature Search

One area of focus in the NEWBio research has been to learn from work already done in countries and areas with established biomass production and processing systems. After researching, it was found that the European Union (EU) and particularly Western Europe have a large and well-established biomass production system with a research system in place, as described by Venendaal et al. (1997). Research in this area began by searching for biomass production information in the EU. Significant research has been done in Europe on using biomass and energy crops to produce energy. Several countries have well-established biomass systems that have been running for several years. A systematic search was completed using the terms included in references and the Google search engine. Each link, document, and presentation that had applicable material was read and searched for information pertaining to biomass logistics and safety on farms and during transport. Any possible contacts were kept and stored in case further contact was needed. Following the web search, several sources in a biomass hub in northern Spain were identified and contacted to get more information regarding biomass logistics.

To determine what safety issues might be present, a representative of CENER (Centro Nacionale de Energias Renovables), a biomass research center in Navarra, Spain, was contacted and interviewed on-site by the fifth author. A tour of the plant was offered, and all safety questions were answered. In addition, a list of possible sources on safety in the biomass industry was obtained. The visit to CENER was beneficial on several levels. It provided an opportunity to view a biomass system that has been well-established for several years and gain an understanding of how that system was designed. A better sense of the safety hazards that CENER has encountered in biomass production and the risks that biomass poses was also obtained. The logistical difficulties of biomass use, and how power plants in northern Spain deal with these problems through careful collaboration with partners to ensure a consistent supply of biomass, were also discussed (D. Sánchez, personal communication, 3 January 2013).

A publication of the International Energy Agency (IEA) Bioenergy Task32 task force covers health and safety aspects of solid biomass storage, transportation, and feeding (IEA Bioenergy, 2013). This publication focuses primarily on wood chips and wood pellets and includes fire, dust explosion, respiratory, and harvest hazards. Harvest hazards covered are related to large forestry operations, while other hazards are related to large industrial processing operations. The transport of straw is covered briefly; on-farm hazards of dedicated biomass crops are not covered.

The results of the international research revealed that countries with established biomass systems have not researched on-farm safety hazards unique to the biomass industry nor developed any specific programs to address safety in any areas of the biomass industry. The publication mentioned above documents practices at current large-scale biomass operations that are based on experiences at these large heat or power plants. Research-based safety information on the agricultural production side does not appear to exist. Several common hazards, such as fires in storage, dust explosions, and falls, have been identified, but little research has been done to mitigate these hazards, as detailed by the Combustion Engineering Association (CEA, 2011). However, European processing facilities separate storage areas from combustion areas in order to prevent fires and fire-spread (D. Sánchez, personal communication, 3 January 2013). No international safety protocols were found that addressed farm-level biomass production.

U.S. Literature Search

Following the search done on biomass safety on an international scale, a search was completed for safety information in the U.S. This was completed using three sources: the Google search engine, the Penn State University Library database search engine, and the

ASABE Technical Library. The Penn State University Library database search engine searches Agricola, Biological Abstracts, and many other databases. This search engine, called Summon, is licensed from Serials Solutions and provides a single gateway to search the extensive electronic resources of the libraries. Thirty papers were identified, read, and examined, and the most pertinent papers are summarized below.

Biomass Storage and Handling: Status and Industry Needs is an ASABE annual meeting presentation that provides a summary of the current status of the biomass industry (Williams et al., 2008). This paper covers the growth in the use of biofuels, types of biomass being used for fuel, forms of biomass, and types of storage systems used. The paper also addresses the pelletization of biomass and transport of biomass within a processing facility. The paper does not address potential safety issues, nor does it mention the terms "safety," "health," "hazard," "risk," "accident," or "injury." When addressing and summarizing industry needs, the paper focuses on engineering challenges but does not mention any need for safety standards or research.

Terminology and Definitions for Biomass Production, Harvesting and Collection, Storage, Processing, Conversion, and Utilization was published as an ASABE Standard in January 2011 (ASABE, 2011). The purpose of the standard was to include "all the terminologies that are used in biomass feedstock production, harvesting, collecting, handling, storage, preprocessing and conversion, bioenergy, biofuels, biopower, and biobased products." This was done to provide uniform definitions and terms that could be used in biomass production. There is no mention of the terms "safety," "health," "hazard," "risk," "accident," or "injury" within the standard. The standard does not address any terms that relate directly to biomass safety.

A Review on Biomass Classification and Composition, Co-firing Issues, and Pretreatment Methods is an ASABE annual meeting presentation (Tumuluru et al., 2011). This paper addresses the state of the biomass industry and the possibility of co-firing biomass with coal. Specifically, the paper examines the costs of adapting current coal plants to co-firing, feedstock constraints, logistical issues, and methods for preprocessing biomass material. The paper mentions health and safety risks three times in passing, in reference to technical considerations, conveying biomass fuel, and the potential for dust explosions from biomass ash. The paper does not specifically address any safety issues during biomass production or processing. While the equipment used for extrusion and compaction is discussed, safety is not discussed.

A Technical Review on Biomass Processing: Densification, Preprocessing, Modeling, and Optimization is an ASABE annual meeting presentation (Tumuluru et al., 2010). This paper focuses on increasing the density of biomass materials to increase their application for fuel production. The paper covers methods for densifying biomass material as well as the potential effects on the material due to increasing its density. There is no mention of the terms "safety," "health," "hazard," "risk," "accident," or "injury."

Engineering Factors for Biomass Baler Design is an ASABE annual meeting presentation (Lanning et al., 2007). This paper addresses the possibility of baling urban biomass using a biomass baler. Most of the paper focuses on the engineering issues and constraints associated with biomass balers. However, the paper also mentions the significant safety risks from biomass bales falling due to being stacked in piles. The paper contains no mention of the terms "health," "hazard," "accident," or "injury."

Shear Processing of Wood Chips into Feedstock Particles is an ASABE annual meeting presentation (Lanning et al., 2012). This paper focuses on processing cellulosic biomass into small particles to be used for fuel. A study is done of the process of chipping the biomass using a rotary shearhead. The paper addresses the hazards of using a rotary shearhead and the potential for entanglement of loose clothing or fingers. The paper includes the terms "safety," "health," and "hazard." The paper also addresses engineering controls that can be used to reduce the risk of entanglement.

Bioenergy Plant Precautions is a magazine article published in the March 2013 issue of *Biomass Magazine* (Simet, 2013). This article focuses on several safety hazards present in biofuel plants. These include fires due to biomass overheating, electrical hazards, dust explosions, and equipment overheating. This article includes the terms "health," "safety," "hazard," "risk," and "accident."

Following the literature review, the information gathered was compiled. Each search term was recorded. No publications were found that specifically addressed the range of hazards associated with the planting, production, and preprocessing of biomass.

Recent papers or articles published by ASABE on the topic of biomass include publications comparing forage equipment used to process short-rotation woody crops (Savoie et al., 2013b), particle size measurement of specific biomass species (Savoie et al., 2013a), torrefaction of biomass (Wei et al., 2013), spectroscopy (Williams et al., 2013), and energy requirements for cutting biomass (Maughan et al., 2013). None of these papers or others found with the search terms "biomass," "switchgrass," "miscanthus," or "willow" included safety issues.

Tracking Injuries in Biomass Production Systems

The current literature does not appear to group injuries related to biomass systems by industry codes or other methods to easily identify the cases. There are several possible reasons for this. With all the different sources of biomass, the industry classifications are segmented over several different industries. In the North American Industry Classification System (NAICS), there are several industry codes for biomass crops (U.S. Census Bureau, 2013). For instance, switchgrass and miscanthus production best fit under NAICS 111940: Hay Farming, but short-rotation (less than ten years per cycle) willow production fits under NAICS 111421: Nursery and Tree Production. Yet another biomass feedstock, wood chips, could fit under NAICS 113310: Logging Industry. This leads to segmented injury and illness data that can be difficult to capture, especially for researchers who may not understand all the potential biomass crops. The term "biomass" was added to the NAICS codes in 2012 under NAICS 201117: Biomass Electric Power Generation. Similar codes could be developed for crop production of biomass feedstock. This may clear up some of the confusion; however, for some crops, part of the crop is used for food and/or fiber, and part of the crop is used for biomass energy production. An example of this split usage is harvesting corn grain for feed and corncobs for biomass energy. An injury occurring during crop planting or maintenance will be difficult to categorize when the resulting crop is used for multiple purposes.

Another way of identifying injuries related to biomass production is the Source of Injury and Type of Event codes used by the Bureau of Labor Statistics (BLS) within the industries identified as producing biomass. Both of these codes are part of the BLS Occupational Injury and Illness Classification System (OIICS) (CDC, 2013). Table 2 provides a summary of some of the more common sources of injury and types of events that

Table 2. Anticipated injuries in biomass production systems based on source and event.[a]

	Type of Event							
Source of Injury	Violence or injury by person or animal	Transportation incidents	Fires and explosions	Falls, slips, and trips	Exposure to harmful substance or environment	Contact with object or equipment	Overexertion and bodily reaction	Nonclassifiable
Chemical and chemical products								
Acids and alkalines								
Pesticides								
Fuels and lubricants								
Containers, furniture, and fixtures								
Containers								
Skids and pallets								
Lighting fixtures and equipment								
Agricultural machinery								
Harvesting and threshing								
Mowing			A					
Plowing, planting, and fertilizing								
Construction, logging, and mining machinery								
Excavating machinery								
Loaders								
Logging and wood processing								
Parts and materials								
Tarps and sheeting								
Vehicle and mobile equipment parts								
Persons, plants, animals, and minerals								
Animals								
Animal and plant byproducts			B					
Person								
Plants, trees, vegetation, not processed								
Structures and surfaces								
Confined spaces								
Buildings								
Floors, walkways, and ground surfaces								
Tools, instruments, and equipment								
Hand tools, powered and non-powered								
Ladders								
Vehicles								
Highway vehicles, motorized								
Animal and human powered vehicles								
Off-road and industrial vehicles								
Industrial vehicles and material hauling								
Tractors and PTOs								
Other sources								
Scrap, waste, and debris								
Other steam, vapors, liquids, and ice								

[a] Based on the BLS Occupational Injury and Classification System (OIICS): wwwn.cdc.gov/wisards/oiics/.

lead to injuries in biomass systems. The Source of Injury and Type of Event categories are an abbreviated version of the BLS OIICS. The shaded boxes represent some of the anticipated injuries in biomass production.

Some of these injuries have similar sources and events as production agriculture, but there are also some sources and events that may be unique to biomass production. For example, two types of fires that commonly occur in biomass production systems have been identified by our research. Fires can occur when switchgrass, which has been allowed to dry while still standing in the field, is being mowed and the mowing machinery creates a spark or ignition source. If someone was injured by this event, it would be classified in the box labeled "A" in table 2, at the intersection of the "Fires and Explosions" Type of Event and the "Mowing" Source of Injury. The second type of fire occurs during storage of biomass. Fires can start if biomass is baled and stored at the wrong moisture content. If someone was injured by this event, it would be classified in the box labeled "B" in table 2, at the intersection of the "Fires and Explosions" Type of Event and the "Animal and Plant Byproducts" Source of Injury.

Safety and Health Regulations

Industry codes in biomass production are also important with regard to safety and health regulations. For instance, farms with family labor or with fewer than eleven employees are exempt from federal Occupational Safety and Health Administration (OSHA) regulations. However, if a farm or ranch employs eleven or more workers, most safety and health regulations apply. If a biomass producer of any size processes biomass material, e.g., bags and sells biomass seed or densifies biomass into pellets or briquettes, OSHA may consider this part of the operation as not being production agriculture and can apply all safety and health regulations to that operation even if there is only one non-family employee. This line of reasoning was recently applied to grain drying operations on family farms, as OSHA interpreted the grain drying as a non-farming activity. An OSHA memo dated 28 June 2011 described the reasoning for including this type of post-harvest processing under OSHA requirements even though non-OSHA farms are explicitly exempted from these requirements. The original memo is no longer available on the OSHA website and has been superseded by a memo dated July 29, 2014 (Galassi, 2014). Efforts were made to reverse the original OSHA interpretation (Johanns, 2013), and these efforts were successful (Ag and Food Law Blog, 2014). This is an important issue to continue monitoring, as more farms are participating in "value-added" activities and may unknowingly come under OSHA regulations.

Minimizing Biomass Production Hazards and Risks

William Haddon Jr., an MD and the first administrator of what today is the National Highway Traffic Safety Administration, was a pioneer in highway accident research and prevention. He was among the first to identify that human injury is a problem of excessive energy exchange between humans and material objects (Haddon, 1963) and that engineering strategies are among the most promising strategies for large-scale, long-term reduction of injury and injury severity (Haddon, 1970). Haddon also recognized that injury events often follow the form of many diseases (Haddon, 1968), including the time before the onset of the disease (first phase), the time when the disease process is most active (second phase), and the time immediately after the most active disease process (third phase). Finally, he recognized that several factors are involved in vehicle crashes, including drivers, passengers, other vehicles, road surfaces, and bad weather. Haddon suggested combining the phases and factors into a matrix that would help identify opportunities for influencing the end results.

The Haddon matrix was first presented in 1972 (Haddon, 1972). The matrix is a multiple countermeasure framework that helps identify opportunities to prevent damage to people, the things we use, and the physical environment. These opportunities exist prior to a damaging event, during the most active part of the damaging event, and after the damaging event (Haddon, 1968). The matrix is adaptable and can be used to organize a rational approach to hazards and risks in many different fields. Some form of the Haddon matrix is referred to in most public health texts on hazards and injury (e.g., Robertson, 1998; Geller, 2001).

Applying the Haddon matrix to biomass production hazards and risks helps to identify possibilities for preventing, mitigating, and repairing injury to the workers, and damage to the equipment, products, and structures used, and damage to the physical environment that surrounds biomass production.

Table 3 identifies a range of ideas for addressing safety and health issues involving farm-level biomass production and storage. This matrix is meant to serve as a basis by which safety and health interventions involving engineering, education, and policy might be considered. The matrix is neither static nor prescriptive; it is a dynamic tool to aid in thinking about actual and possible injury control efforts.

When reading across the matrix, it is important to understand that the opportunities identified within adjacent cells are not correlated with each other. For example, in the Event row, “Fall arrest systems” does not correlate with “Auto-shutoff of overturned equipment” or “Have multiple workers onsite.” However, when reading down the matrix, the cells can be considered correlated because they all address opportunities involving either workers, things, or the environment.

A project investigating biomass feedstock production is considering risk-assessment tools for the on-farm biomass industry (Schwab, 2013). This work investigates the use of a number of different risk-assessment tools common to industrial risk assessment and adapts those tools to on-farm biomass production. The outcome of this research will be one or more risk-assessment tools that can be used for reducing hazards in on-farm biomass production.

Currently, the following topics and risk-assessment tools are under review: hierarchy for actions, frequency and severity, deviation analysis, and fault tree analysis. The initial portion of this work creates a structure of the tasks or steps involved in biomass feedstock production, breaking each task down into small, discernible steps. An example of these steps for the task “Seedbed Preparation” is shown in figure 2. When these small, individual steps have been identified, a risk matrix of severity versus frequency can be made for the identified actions. An example of such a matrix is shown in figure 3.

Deviation analysis looks at the large number of possible, simultaneously occurring deviations that lead toward an injury. By examining these simultaneous deviations, the relationships between the actions and deviations can be explored. Figure 4 shows an example of this type of analysis.

Another method of looking at events that may lead to injury is fault tree analysis. This method of analysis uses Boolean logic (and/or logic) to combine a series of events that lead to the undesired state of failure or injury (fig. 5).

As these risk-assessment tools are developed and evaluated for application to on-farm

Table 3. Haddon matrix applied to biomass production system hazards and risks.

	Factors		
Phase	Workers	Equipment, Products, and Structures	Physical Environment
Pre-event	Safety and health management plan for biomass operations. Safety and health training for: -Personal protective equipment. -Agricultural hand signals. -Special populations (young, immigrant, aged, etc.). -Equipment on public roads. -Securing loads for transport. -Dealing with fires. -Safe operation of biomass equipment. -Safe application of pesticides and fertilizers. Best safety practices for biomass production and storage. Separate management and labor functions.	Tractors with rollbars and seat belts. Machines properly guarded. Interlocking guards and sensors. Proper lighting and marking of equipment. Equipment with reverse gathering mechanisms. Properly sized equipment Heat detection and sensor systems. Safe truck hauling procedures. Safe facility layout (fuel tanks, size of storage structures, etc.). Stability monitoring devices. New designs to assist extraction from equipment and structures.	Limit degree of slopes for planting and harvesting. Clear obstructions for safe entry and exit of lands. Confined spaces. Provide field sanitation facilities. Heaters or shelter for cold weather activity. Shade and water for hot weather activity. Engineering controls to reduce environmental hazards. Optimization of road travel to limit exposure. Adapting equipment and practices for winter conditions (northern climates).
Event	Equipment occupant restraints. Fall arrest systems.	Tractors with rollbars and seat belts. Auto-shutoff of overturned equipment. Fuses and slip clutches. Sprinkler systems in storage structures. Fire extinguishers on equipment. Safe procedures for pulling out stuck equipment.	Communicating in areas of limited cellphone coverage. Have multiple workers onsite. Availability of firefighting resources (water, volunteer firefighters, etc.). Safe entry into confined spaces.
Post-event	Ability to notify EMS. Farm worker emergency response training. First aid and CPR training. Insurance coverage.	GPS locators. Insurance coverage.	Access of emergency responders to incident sites. Emergency helicopter landing availability. Trained emergency responders available. Proximity to hospitals or trauma centers.

biomass production, differences between industrial and farm-based operations become apparent. These tools have been developed for industrial applications, and agricultural production and the on-farm production of biomass will not be a perfect fit for these applications. Farming is a decentralized system of production, contrary to industrial production. Farming often involves family labor and may combine household activities with production activities. As a result, it is often difficult to separate work and home tasks.

While biomass production ramps up to larger volumes, some agricultural production methods currently in use may not work for the anticipated large-scale production systems. Documentation of the safety and health hazards of conventional agriculture may not apply to biomass production. For example, the current method of stacking bales for

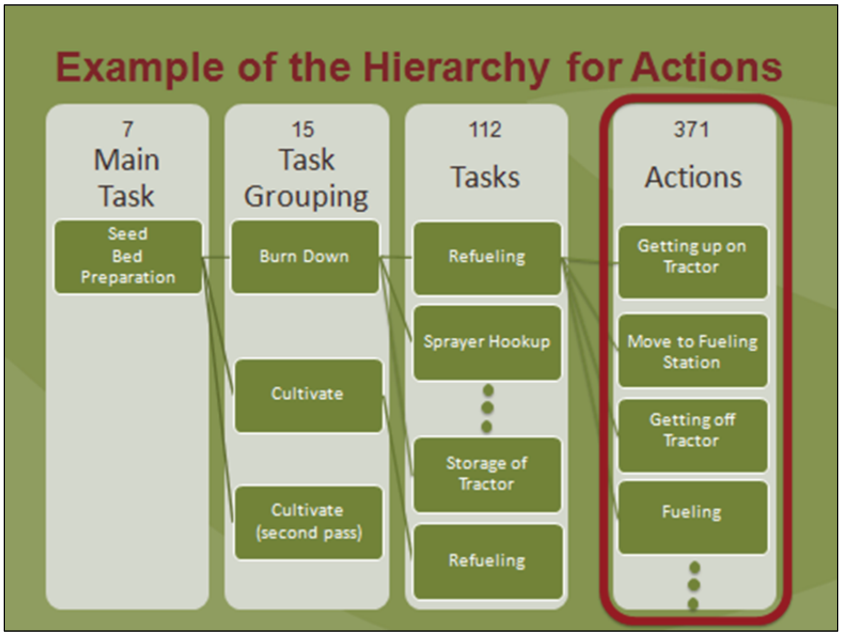


Figure 2. Tasks broken down into individual actions.

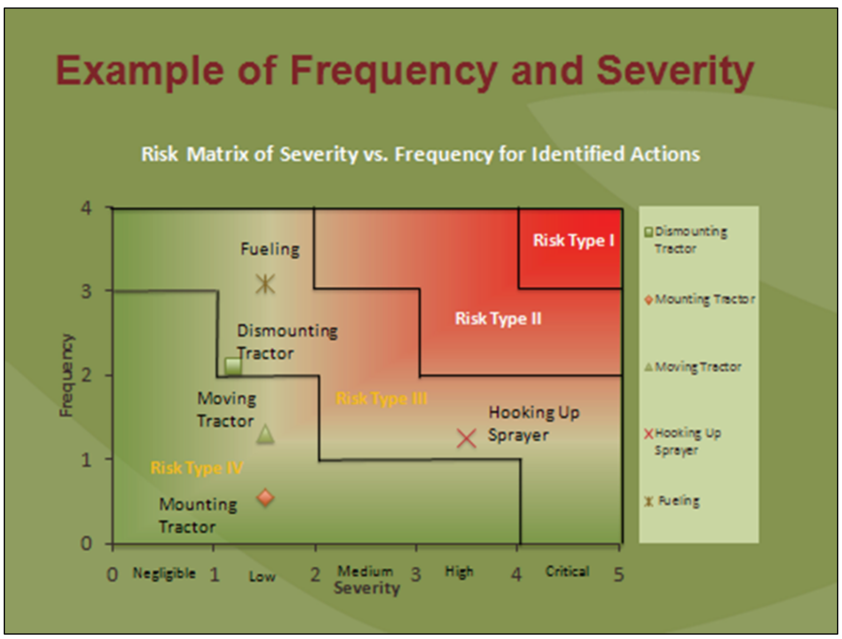
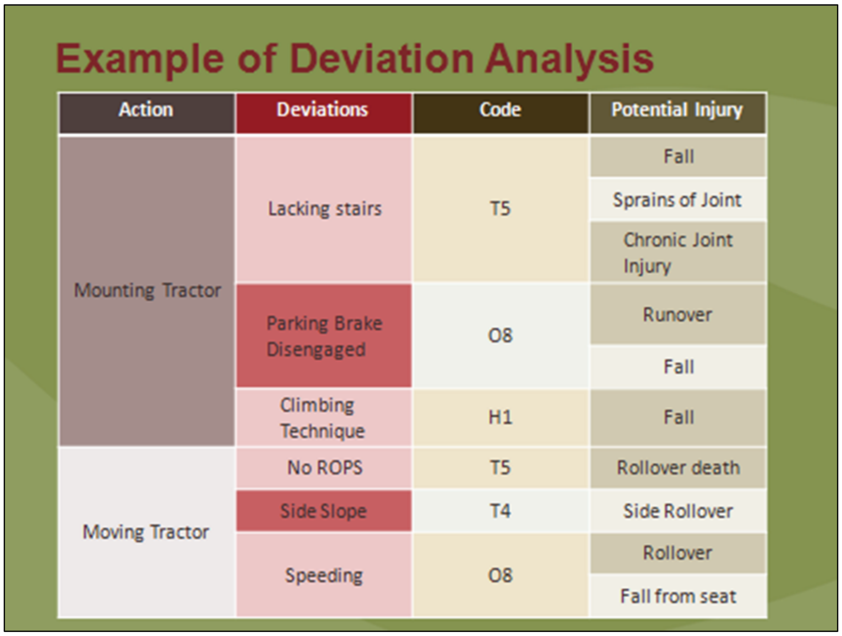


Figure 3. Severity vs. frequency matrix for identified actions.



Example of Deviation Analysis

Action	Deviations	Code	Potential Injury
Mounting Tractor	Lacking stairs	T5	Fall
			Sprains of Joint
			Chronic Joint Injury
	Parking Brake Disengaged	O8	Runover
			Fall
	Climbing Technique	H1	Fall
Moving Tractor	No ROPS	T5	Rollover death
	Side Slope	T4	Side Rollover
	Speeding	O8	Rollover
			Fall from seat

Figure 4. Deviation analysis for identified actions.

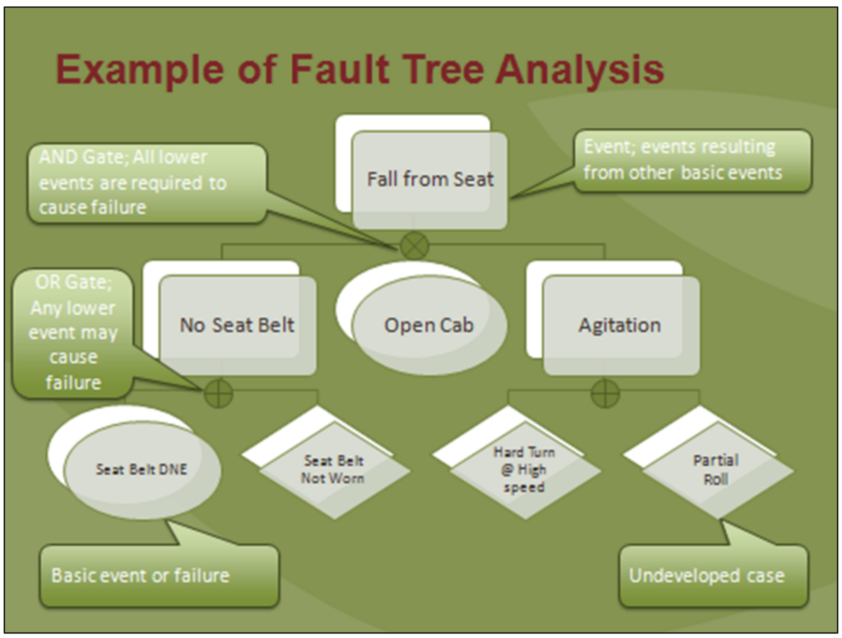


Figure 5. Boolean fault tree analysis.

storage may not work, as larger volumes of feedstock are required. An entirely new system of biomass storage may be necessary to replace conventional agricultural storage, and the current knowledge of hazards inherent in bale storage may no longer apply. New research into the safety and health hazards of on-farm biomass production, storage, and transport will be necessary as innovative approaches are tried and brought into practice.

Summary

Following a comprehensive search on safety protocol and information in the biomass production and processing industries, both in the U.S. and internationally, very little evidence was found of analysis or attention devoted to specific issues relating to health and safety in biomass production, processing, and transport. While safety protocols and research have been done on equipment similar to that used in the biomass industry, they are not specific to biomass and do not factor in the unique conditions present in energy crop production. Even in the EU, where biomass production has almost doubled in the last ten years, safety and health appears not to have been a significantly reviewed factor and has not been examined, as gathered from Eurostat (European Commission, 2012).

With the rapid expansion of biomass production and storage on farms and ranches, now is the time to integrate injury and illness surveillance and prevention programs. Safety and health should be an integral part of the design and use of biomass systems. Implementation of the Haddon matrix and other safety and health management tools is essential throughout the expansion of biomass systems.

In conclusion, the materials presented here represent a beginning for safety and health in biomass production. Future reviews and studies are encouraged to contribute to the body of knowledge related to this important topic, including injury surveillance, identification of unique or modified equipment, processes, and hazards, application of safety and health regulations, and development or extension of safety and health standards.

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References

Ag and Food Law Blog. (2014). OSHA withdraws enforcement memo on grain bin safety. Fayetteville, Ark.: National Agricultural Law Center and American Agricultural Law Association. Retrieved from www.agandfoodlaw.com/2014/02/osha-withdraws-enforcement-memo-on.html.

ASABE. (2011). ANSI/ASABE S593.1: Terminology and definitions for biomass production, harvesting and collection, storage, processing, conversion, and utilization. St. Joseph, Mich.: ASABE.

CDC. (2013). Occupational Injury and Illness Classification System (OIICS). Atlanta, Ga.: Centers for Disease Control and Prevention. Retrieved from http://wwwn.cdc.gov/wisards/oiics/.

CEA. (2011). Health and safety in biomass systems: Design and operation guide. Sedgefield, U.K.: Combustion Engineering Association. Retrieved from www.cea.org.uk/files/4313/7502/0795/Biomass_HS_final_071211.pdf.

European Commission. (2012). Primary production of renewable energy, 2000 and 2010. Brussels, Belgium: European Commission, Eurostat. Retrieved from http://epp.eurostat.ec.europa.eu/statistics_explained/index.php?title=File:Primary_production_of_r

enewable_energy,_2000_and_2010.png&filetimestamp=20121012133631.
FAO. (1999). Chapter 2: Definitions and contexts. In *CGIAR Research Priorities for Marginal Lands*. Rome, Italy: United Nations FAO. Retrieved from www.fao.org/Wairdocs/TAC/X5784E/x5784e05.htm.
Galassi, T. (2014). Memo: Policy clarification on OSHA's enforcement authority at small farms. Washington, D.C.: Occupational Safety and Health Administration. Retrieved from https://www.osha.gov/dep/enforcement/policy_clarification_small_farms.html.
Geller, E. S. (2001). *The Psychology of Safety Handbook*. New York, N.Y.: Lewis Publishers.
Gunderson, P. (2013). Storing and shipping biomass: Health and safety implications. Presentation at the North American Agricultural Safety Summit. Marshfield, Wisc.: Agricultural Safety and Health Council of America.
Haddon, W., Jr. (1963). A note concerning accident theory and research with special reference to motor vehicle accidents. *Ann. New York Acad. Sci., 107*, 636-646.
Haddon, W., Jr. (1968). The changing approach to the epidemiology, prevention, and amelioration of trauma: The transition to approaches etiological rather than descriptively based. *American J. Public Health, 58*(8), 1431-1438. http://dx.doi.org/10.2105/AJPH.58.8.1431.
Haddon, W., Jr. (1970). On the escape of tigers: An ecologic note. *American J. Public Health, 60*(12), 2229-2234.
Haddon, W., Jr. (1972). A logical framework for categorizing highway safety phenomena and activity. *J. Trauma, 12*(3), 193-207. http://dx.doi.org/10.1097/00005373-197203000-00002.
IEA Bioenergy. (2013). Health and safety aspects of solid biomass storage, transportation, and feeding. Paris, France: International Energy Agency. Retrieved from www.ieabioenergy.com/publications/health-and-safety-aspects-of-solid-biomass-storage-transportation-and-feeding/.
Johanns, M. (2013). Letter to Hon. Thomas Perez, Secretary, U.S. Department of Labor. Retrieved from www.johanns.senate.gov/public/?p=PressReleases&ContentRecord_id=96d7a8a9-a613-4a11-aefd-27c971fdb0b7.
Lanning, D., Dooley, J., DeTray, M., & Lanning, C. (2007). Engineering factors for biomass baler design. ASABE Paper No. 078047. St. Joseph, Mich.: ASABE.
Lanning, D., Dooley, J., & Lanning, C. (2012). Shear processing of wood chips into feedstock particles. ASABE Paper No. 121337113. St. Joseph, Mich.: ASABE.
Maughan, J., Mathanker, S., Grift, T., & Hansen, A. (2013). Impact of blade angle on miscanthus harvesting energy requirement. ASABE Paper No. 131596571. St. Joseph, Mich.: ASABE.
NEWBio. (2011). Project proposal. University Park, Pa.: Pennsylvania State University, NEWBio. Retrieved from www.newbio.psu.edu/about.asp#focus.
NEWBio. (2013). About NEWBio: Feedstock focus 2012. University Park, Pa.: Pennsylvania State University, NEWBio. Retrieved from www.newbio.psu.edu/about.asp.
Perlack, R., Wright, L., Turhollow, A., Graham, R., Stokes, B., & Erbach, D. (2005). Biomass as feedstock for a bioenergy and bioproducts industry: The technical feasibility of a billion-ton annual supply. Oak Ridge, Tenn.: Oak Ridge National Laboratory.
Robertson, L. S. (1998). *Injury Epidemiology: Research and Control Strategies* (2nd ed.). New York, N.Y.: Oxford University Press.
Savoie, P., Pilon, G., & Mani, S. (2013a). Particle size measurement by static and dynamic image analysis for processed woody biomass crops. ASABE Paper No. 131578073. St. Joseph, Mich.: ASABE.
Savoie, P., Hebert, P., & Robert, F. (2013b). Harvest of short rotation woody crops with small to medium size forage harvesters. ASABE Paper No. 131620174. St. Joseph, Mich.: ASABE.
Schwab, C. (2013). Issues associated with risk analysis in biofeedstock production. Presentation at the North American Agricultural Safety Summit. Marshfield, Wisc.: Agricultural Safety and Health Council of America.
Simet, A. (2013). Bioenergy plant precautions. *Biomass Magazine*, 7(3) (March), 18-23. Retrieved from http://biomassmagazine.com/articles/8697/bioenergy-plant-precautions.

Tumuluru, J., Wright, C., Kenney, K., & Hess, J. (2010). A technical review on biomass processing: Densification, preprocessing, modeling, and optimization. ASABE Paper No. 1009401. St. Joseph, Mich.: ASABE.
Tumuluru, J., Sokhansanj, S., Wright, C., Boardman, R., & Yancey, N. (2011). A review on biomass classification and composition, co-firing issues, and pretreatment methods. ASABE Paper No. 1110458. St. Joseph, Mich.: ASABE.
U.S. Census Bureau. (2013). The North American Industry Classification System (NAICS). Washington, D.C.: U.S. Census Bureau. Retrieved from www.census.gov/eos/www/naics/.
U.S. DOE. (2011). U.S. billion-ton update: Biomass supply for a bioenergy and bioproducts industry. ORNL/TM-2011/224. Oak Ridge, Tenn.: Oak Ridge National Laboratory.
U.S. EIA. (2013). Monthly energy review: January 2013 DOE/EIA-0335(2013/01). Washington, D.C.: U.S. Energy Information Administration. Retrieved from www.eia.gov/totalenergy/data/monthly/previous.cfm#2013.
Venendaal, R., Jørgensen, U., & Foster, C. A. (1997). European energy crops: A synthesis. *Biomass Bioenergy, 13*(3), 147-185.
Wei, L., Qu, W., Julson, J., Chunkai, S., & Zhao, X. (2013). Experimental study on torrefaction of corn stover, switchgrass, and prairie grass. ASABE Paper No. 131585924. St. Joseph, Mich.: ASABE.
Williams, D., Danao, M., Paulsen, M., Rausch, K., Ibanez, A., & Bauer, S. (2013). Partial least squares discriminant analysis (PLS-DA) of *Miscanthus* × *giganteus* by FT-NIR spectroscopy. ASABE Paper No. 131596145. St. Joseph, Mich.: ASABE.
Williams, G., Jofriet, J., & Rosentrater, K. (2008). Biomass storage and handling: Status and industry needs. ASABE Paper No. 082081. St. Joseph, Mich.: ASABE.