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Biomass Gasification: A Comprehensive Demonstration of a Community-Scale Biomass Energy System

Final Report to the USDA Rural Development
Grant 68-3A75-5-232

Chapter 6: Guidelines for Developing a Sustainable Biomass Supply Chain

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1 Establishing a Sustainable Biomass Supply Chain

Energy produced from renewable sources, such as biomass, is being heavily researched due to the recent volatility in fossil fuel energy prices. However, the process of using these alternative energies requires the development of new supply chains and a labor pool to manage them. Some technologies, like solar and wind energy, are more straightforward in that the equipment captures natural energy in its immediate environment, converts it to electricity and then moves it to where it is needed via transmission lines. In other words, the energy resource is 'delivered' to the energy conversion technology by nature. However, biomass energy is complicated due to the bulky, distributed nature of biomass feedstocks and the high volumes of the relatively low energy density materials that have to be moved to the conversion equipment.

Arguably, the most difficult component of setting up a biomass energy system is establishing the mechanism to bring enough low density plant biomass to a central point for conversion to energy. There are a number of good technologies for converting biomass into usable energy, but almost all start from tree and plant based materials found spread over the landscape. This document introduces the discussion of setting up a supply chain to collect a distributed biomass resource, such as agricultural or forestry residue. It is based on the experiences of the staff of the Morris Biomass Gasification Project, a research project conducted by the University of Minnesota, West Central Research and Outreach Center (WCROC) and the University of Minnesota, Morris (UMM). The University of Minnesota project involves a biomass-to-energy facility located in a rural agricultural setting, with some access to woody biomass from northern Minnesota.

The large number of conversion technologies, energy uses, and biomass feedstocks make almost every biomass conversion project somewhat unique. In addition, the parties involved will often bring a unique set of skills to a biomass supply chain. Therefore, this document tries to generalize the process. As an example, the experiences from the University of Minnesota Gasification Facility probably would have been quite different had the facility been located in a rainforest or temperate costal area. Also, in the context of this review, biomass energy does not refer to high value plant products such as grain and sugars. These have been used to produce energy, but there are supply chains already in place to provide those products for other uses such as foodstuffs as well as energy.

The unique nature of each biomass project is in stark contrast to the fossil fuel industry model. In the fossil fuel industry, standardization is a key to lowering production costs. The technologies and methods used in finding and delivering fossil fuels have evolved to be efficient and relatively uniformly applied, thus reducing costs. In biomass projects, the distinct features of a particular feedstock in a particular location mean that the collection and delivery systems often have to be specially developed to match a particular project. To match the low costs of fossil fuels, successful biomass energy projects need to start with low cost feedstocks and deliver them cleanly and efficiently to a conversion facility. Proper planning and review are key to developing an efficient supply chain.

Before talking about establishing a supply chain, it is important to understand why setting up a dependable supply chain is important. A well thought out biomass supply chain will keep a more constant and reliable feedstock for the energy conversion process and thus limit risks to capital. A large biomass energy facility can cost hundreds of millions of dollars and require 15 to 20 years to pay back capital costs. Lenders are not likely to back a project that could have feedstock supply issues early in the project. In fact, lenders may require a certain percentage of the feedstock be under long-term contract before any construction activities are financed. Environmental sustainability is also an important concern for a biomass supply chain. Poor environmental planning can hurt the environment, damage the image of biomass energy, and limit available resources. For these reasons and others, it is important that comprehensive planning for the supply chain begins before or at the same time that the energy conversion technology is being discussed. Merely stating that there is available, low cost biomass for conversion to energy based on a number in a United States Department of Agriculture (USDA) or US Forest Service report will not result in a well-developed supply chain.

Though almost all parts of the supply chain are interrelated, this document explains the process of developing the chain by breaking it down into several distinct areas. The first step is identifying locally occurring biomass resources that may be available for use. Once a suitable resource has been identified, the roles of individuals and organizations in the supply chain should be clarified. As these steps are being completed, there should be an examination of the quality control and pre-processing needs for the feedstock. Storage concerns are another large part of a supply chain and should be well thought through. The final analysis of the supply chain should be an overall evaluation of the economics associated with collecting and delivering biomass feedstocks.

2 Identifying Biomass Resources

Finding a suitable biomass feedstock resource is the first part of the supply chain. It is helpful to first review what biomass is and what properties make it suitable for conversion to energy or refining to bio-based products, in order to completely identify all potential sources of biomass for a supply chain. Biomass is material that was formerly living, that has large amounts of energy stored in the carbon- and hydrogen-containing molecules which made up the cell walls, proteins, and carbohydrates of the organism. While most people think of plant material when they hear the term biomass, animal cells and micro-organisms also contain significant amounts of energy. In addition to the beneficial energy biomass holds, biomass often has some less desirable components. Naturally occurring minerals and compounds in biomass can complicate its conversion to energy. Plants in the grass family tend to have high levels of silica forming part of their rigid stem structure, which can be problematic for some thermal conversion systems. A common component in biomass is water or moisture. Biomass conversion technologies are usually selected to minimize complications due to contaminants or undesired properties. As an example, combustion or gasification systems are often limited in their ability to handle wet fuels and thus need fuel drying equipment to operate with a wet feedstock, whereas cellulosic ethanol production often requires that the material be in a water based suspension to allow microorganisms to convert biomass to ethanol. Identifying the undesirable properties of biomass resources is important early in supply chain development as it will influence other factors such as storage, processing, and conversion technologies.

Biomass resources can be broken down roughly into three broad categories: agricultural, forestry, and industrial by-products. Agricultural biomass typically includes biomass that remains on the field after the harvest of a primary product (e.g. grain), specially grown energy crops, and other on-farm materials such as litter/manure. Typical forestry biomass products include slash material/residue, specially planted high biomass woody species, and municipal/utility required tree removals. In both agricultural and forestry situations, the biomass is distributed over the landscape and requires a mechanism to harvest and transport the material to a central point. Although the scale and equipment is very different, the principles of agricultural and forestry biomass supply chains are fairly similar.

Industrial by-product supply chains use secondary or co-products from another operation as biomass feedstocks. Projects using these resources are typically designed as a creative means of using a co-product for on-site energy production rather than finding other more costly methods of disposal. Since the biomass energy project is often co-located with the industrial facility, there is not always a major supply chain associated with the energy feedstock. The industrial facility already has a chain to supply it with raw materials; therefore, the energy feedstock can be referred to as a captured resource. In other words, the feedstock has been centralized for another reason. Typical captured biomass resources include millwork scrap, paper plant black liquor, municipal waste, and sewage sludge. Because there is not a collection/aggregation component in supplying industrial components, storage and on-site logistics are the main issues in managing these feedstocks.

Although there are many lists of potential biomass resources, including Table 1, it is more important to first focus on why biomass resources can or should be used for energy purposes. There are generally two reasons for switching to biomass energy: reduced dependence on energy that has volatility in price/supply, and environmental benefits. In economics terms, it is important that the relatively low bulk (and energy) and low density materials be low cost, at least as they are found distributed across the landscape. Collecting and transporting these materials to a central location is required to make them useful and is a fairly expensive process. If the materials were already expensive as they lay in a field or forest, the cost of the logistics to get them to a facility would make energy production economically unfeasible.

Environmentally, the largest benefit from biomass energy is the reduction in use of fossil fuels and subsequent release of long sequestered CO_2. Biofuels release CO_2 during the conversion process, but the CO_2 they release is recaptured by the plants during the next growing cycle. Therefore, there is no net release of carbon. There are other benefits in removing excess biomass from the landscape, whether it is too much residue on an agricultural field, a high amount of dry forest litter prone to fire, or diseased/weedy material that needs removal. However, there are also some sustainability issues associated with using biomass.

Selecting biomass resources is about ‘picking the low hanging fruit’; that is, the cheapest biomass that can still generate economical and sustainable energy. Since the sheer volume of feedstock needed is large and supply chain costs can be high, inexpensive biomass is the key. The first step in developing a supply chain is to identify all the possible biomass feedstocks available in proximity to the proposed facility (Figure 1). Even those feedstocks identified as being in short supply should be documented. Information on potential biomass feedstocks can be provided by several sources including the USDA, local business/manufacturing firms, and local utilities/municipalities. Compiling this information is fairly straight-forward, but often takes some time to collect, research and organize. There are consulting firms who work in this area and can add their skills and knowledge to the process, but much of the basic information is publicly available. The data that are required at this point are: a list of biomass resources, the total tonnage of the biomass available annually, and the patterns of availability for each type of biomass.

With the list of available feedstocks in hand, the next step is to match those available feedstocks with compatible energy production technologies. At present, biomass energy has been mostly used to produce steam for heat and electrical generation. These uses favor dry biomass which performs well in thermochemical conversion processes (combustion, gasification, and pyrolysis). In the case of combustion, using 'clean' biomass can greatly reduce the amount of cleanup (scrubbing) needed to maintain acceptable levels of pollutants in facility emissions. Emerging conversion technologies (production of cellulosic ethanol, hydrogen, or dimethyl ether) are likely to have preferred feedstocks based on the physical and chemical performance of the feedstock in energy production.

Once a decision has been made about the desired technology and likely feedstocks, the feedstock availability must be evaluated. The quantity of feedstock needed can be calculated based on the conversion rate of the technology and the amount of energy needed. For example, with a conversion rate of 90 gallons of ethanol per ton of wheat straw and a production capacity of 10 million gallons, a facility needs around 110,000 tons of wheat straw. This is the point at which the business plan for the facility needs to be aligned with the capabilities of the community to supply biomass. It may be that an energy production facility is envisioned that far exceeds local biomass supplies. Accurately assessing the availability of biomass is difficult. Using data from reports on acreages of crops or forested acres may give you a maximum theoretical amount of the material in a given area. However, the reality is that factors such as economics, cultivation practices, weather, and sustainability will play a role in determining the true availability of material.

Economically, feedstocks can be unavailable if their harvest, collection, and delivery costs will not allow profitable energy production. Harvesting biomass in an area with rough terrain, high water-tables, or poor road access can be cost prohibitive. Reports discussing grain or timber removed from land have very little data on the economic suitability of land for harvesting biomass feedstocks. Transportation costs of low density feedstocks can be prohibitive and there is a limit to the distance they can be transported before they become too costly. Thus biomass available for the facility is limited to the feedstock found within that distance. While an early rule of thumb in some early United States Department of Energy (DOE) reports used 75 miles as a limit to economically viable transportation, the true limits will vary by feedstock, transportation costs, and the price paid for the energy produced.

Participation rate is an important component of biomass availability; this refers to the number of biomass producers/landowners willing to participate in biomass energy by selling their residues. Early DOE and USDA estimates relied exclusively on agricultural and forestry production data to calculate how much biomass was available. However, the people who own that resource may not want to participate in its sale for a variety of reasons. An important consideration for many of them is the extra effort required to collect the material. In the case of agriculture, many biomass residues are harvested in the fall when labor and equipment is at a premium. It is also important for them to finish harvesting before winter weather. Another factor in their decision is the need to balance the added revenue with the need to maintain the fertility of their land. Producers know that there are environmental risks from over-harvesting land. Rather than subjecting their land to the smallest risk, they chose to leave litter in the fields/forests. A final reason may be that the amount of money offered for the biomass does not compensate them for their time, equipment, and input costs. Because each farmer/forester makes this decision for their own reasons at different points in time, it is hard to determine long term participation rates. Currently, in developing biomass to energy ventures, most project organizers are using mid-length (typically 3 to 8 years) contracting options to secure a portion of the projected feedstock needed and get a sense of the participation rate before commencing construction. If the project doesn't get started the producer will be released from the contract.

Sustainability is also a factor in how much biomass feedstock is available. Early discussions assumed that if the biomass material was not harvested for its primary use, it was a 'waste' product that could be used for an energy feedstock. However, soil scientists have long been aware that aboveground residues and slash are important components of the soil ecosystem. When left on the ground, biomass will decay and release nutrients such as nitrogen, phosphorus and potassium back to the soil. As the material breaks down, small pieces of decaying plant material become part of the organic material found in healthy soils. This organic material is important because it holds water, prevents nutrient leeching, and maintains soil structure. In addition to soil fertility benefits, residue laying on the soil surface provides protection from rain and wind erosion. Though the exact amounts needed to maintain soil fertility and prevent erosion are not fully understood, early work suggests that there is a percentage of biomass that can be removed on a regular basis. Establishing concise best management practices for biomass harvests is difficult due to the wide variety of management practices combined with soil and climate variation. However, basic guidelines are being put forth to aid producers and landowners in setting up sustainable feedstock harvesting practices. These guidelines should be of assistance when examining the long-term availability of biomass from a given area. Since crop and forest productivity is regional, it is best to look for regionally valid sustainable harvest guidelines to estimate the sustainably available biomass resources.

Another important factor to consider in biomass availability is the anticipated level of supply disruptions due to random occurrences. The natural environment is probably the largest random factor. In agricultural systems, poor weather can reduce or eliminate harvesting of an entire season's worth of biomass. For example, most corn residue harvesting in West Central Minnesota could not be performed during the 2008 and 2009 harvest seasons. Rain and cold weather early in the harvest delayed the grain harvest and, subsequently, pushed residue harvest into winter when snow limited biomass harvests. Forestry operations may face disruptions due to weather or fire, which can reduce availability of timber and slash. Another disruption factor can be the overall economic conditions. The recession of 2008-2009 resulted in a much lower demand for primary wood products in industries such as construction and manufacturing, leading to a much smaller supply of wood by-products such as chipped wood, slash, and sawdust. Though the timing of these random events is unpredictable, the fact that there could be occasional gaps in the availability of a feedstock should be recognized and alternative plans made.

Future availability should also be analyzed for biomass feedstocks. For example, the long term outlook for corn stover availability is fairly solid. Nationwide, the acreages planted to major agricultural crops changes fairly slowly. However, setting up a supply chain based entirely on an industrial byproduct from one newly constructed furniture plant would make the supply chain tightly linked to the success of that one particular plant. The planning process should also consider that feedstock resources could experience competition in the future and that marketplace competition may make resources more expensive. The Minnesota biomass market supplies several facilities that can use the same biomass products, but at this time their primary fuels and geographical distribution does not make competition likely. That being said, these facilities could become competitive buyers for biomass with changes in availability of certain materials or with the addition of new facilities. Supply chain planning should identify those risks and suggest alternatives to mitigate long term availability and competition issues.

One strategy to maintain resource availability and reduce costs is by using multiple feedstocks. There are a number of conversion technologies that can use the same equipment to produce energy from different feedstocks. This is convenient for short term purchasing because it allows purchasing of the cheapest usable biomass at a given point in time. In the long term, it also protects against major availability changes in a feedstock. During project development, fuel flexibility gives an extra margin of error for facilities that may use most of the regionally available pool of a single biomass feedstock. In years where the biomass supply becomes tight, they may need to switch to a more available biomass source. Looking at multiple feedstocks may be the only option for some facilities where one source alone cannot fulfill those facilities' resource demands.

So far, the discussion of biomass availability has focused on its limited availability. This is not meant to imply that biomass availability is limited, but rather to underscore planning factors needed to assure a long term biomass supply. These factors become more critical as the volume of biomass needed for a project increases. For example, a small community-scale heating facility will not necessarily have a demand that exceeds a small portion of the local biomass supply, whereas a large hundred-million gallon per year cellulosic ethanol facility will need biomass from a large area and may experience sporadic feedstock supply shortages if planning did not adequately anticipate glitches in biomass availability. At this scale, the issues of availability and logistics of biomass handling are quite significant. The projected biomass demands for major industrial facilities have prompted more in the industry to consider medium and small scale biomass facilities rather than larger ones.

The final step in biomass resource identification is a thorough review of both the economic and the sustainability aspects of the feedstocks that have been identified. The economics and sustainability should already have been considered, and should be continually monitored throughout development of the supply chain. However, as mentioned above, economics and the environment are ultimately the two main reasons for biomass energy. It should be emphasized that assessments of feedstocks need to include a prediction of the future availability of economically viable feedstocks.

3 Identifying the Parties and their Roles in the Supply Chain

Although some biomass conversion facilities will have the capability to handle all aspects of feedstock logistics from field to facility, most limit themselves to facility operations. While conceptually very simple, the logistics of biomass from the initial harvesting to ultimate use at a facility involves specialized equipment, trained workers, and proper management (Fig. 2). Most biomass energy projects will not have the in-house expertise to conduct all aspects of biomass handling. Additionally, the seasonal nature and intensity of biomass collection for some feedstocks can make it much more efficient to contract for logistic support. Therefore, it is important to identify what activities are needed to support operations of the supply chain on a regular basis and who should complete those activities.

It is helpful to first review different participants and roles that may be involved in the biomass supply chain, plus the resources they can bring to a project. In many cases, individuals or companies take on multiple roles in the supply chain depending on their resources and strengths. The list below is not complete, but includes many of the major roles:

- **Landowner-** Owns the land on which biomass is found. Depending on contractual arrangements, the landowner will also own the biomass found on that land. Past contracts have generally not taken biomass rights into account. However, federal programs such as the Biomass Crop Assistance Program (BCAP) require landowners to sign off that they are allowing biomass to be removed from their land.

- **Farmer/Forester-** Responsible for the crop or timber on a parcel of land. They may also own the rights to the biomass residue, but may have obligation to the landowner to leave organic material on the land. They often have machinery to harvest the grain/timber and residue.

- **Custom Harvester (agriculture)-** Someone who, for a fee, will harvest grain and or residues. Custom harvest operations have expanded over time as equipment costs increased and the critical need for short term help with harvesting has expanded. The custom harvester can often operate their capital intense equipment over a greater number of acres and supply skilled equipment operators to farmers at a lower cost than the farmers could do the work themselves.

- **Custom Harvester (timber)-** Someone who, for a fee, will harvest timber. The custom harvester can often operate their capital intense equipment over a greater number of acres and supply skilled equipment operators to timber managers. Timber managers often don't have the ability to harvest themselves.

- **Transportation-** The economies of scale have promoted the use of tractor-trailer rigs for movement of many products including biomass. Contracting of transportation services offers the ability to move large amounts of biomass relatively quickly without having to invest in trucks and a dedicated labor pool. Contracting transportation is most beneficial for facilities and suppliers that have peak periods of biomass movement. It is not necessarily as cost effective when facilities and suppliers will be transporting material year round for several years.

- **Aggregator-** Most biomass facilities will need such large volumes of biomass that one supplier is not sufficient. An aggregator is a third party who can purchase biomass from several suppliers and make it available as a single large consignment to a facility. At minimum, they simply manage the process of contracting multiple suppliers to fulfill a single contract they have with the facility. However, in practice these firms often have some storage or transportation role.

- **Preprocessing-** Biomass feedstocks may need to be resized (bigger or smaller), dried, or pre-treated with additives depending on facility needs. Depending on the capital investment and throughput for this equipment, it may be more cost effective to have an outside party pre-process materials rather than the biomass facility pre-processing their material. These activities may also require expertise not available at the energy conversion facility.

- **Biomass receiving/shipping-** Receiving may at first seem like an unimportant consideration of simply loading/unloading material. However, even a small biomass plant will need at least one person whose duties include receiving material, managing the storage area, and monitoring the facility's in-feed system. Depending on the circumstances, this can be facility staff or a contracted party.

- **Quality control-** In an ideal world, all biomass received at the conversion facilities would meet the requirements for conversion to energy. However, quality analysis/quality control (QA/QC) is a critical part of many biomass projects, and has been a stumbling block with some projects and technologies. Because of natural variability in feedstocks and changes in feedstocks over time, a good QA/QC program should be an ongoing part of any biomass supply chain.

- **Contract Management**- At the heart of the supply chain, the contract manager watches over all aspects to make sure the plant is getting the material it needs, when it needs it, and at an acceptable quality. Depending on the supply chain there may be multiple contract managers (i.e. one for the facility and one for an aggregator).

A key consideration in how these parties become involved in the logistics operations is the business model for the energy facility. If the facility is a cooperative, it is likely that members of the community and specifically, cooperative members will be involved to the greatest extent possible. The other extreme is a large corporate entity that may already have expertise and capital in all supply chain areas. Facility size and its resulting feedstock demands will also dictate who may be involved in biomass logistics. A smaller facility will have less need for biomass, reducing the work of maintaining the supply chain and also, importantly, may have less ability to pay for added parties in managing the process. A facility demanding a large biomass supply will likely need added oversight, especially with contract management and quality control.

To illustrate possible roles of different parties in supply chains, figure 3 has three examples in which different entities play a role in the biomass supply chain. In the first example (Fig. 3A), a cooperative structure exists where the biomass producers, as a group, own shares in a biomass conversion facility. The large capital costs for the conversion and processing equipment are spread evenly over the cooperating members. These members are then obligated to supply the cooperative with a set amount of material based on their share of the ownership. The shareholders are expected to have access to and the capability of delivering biomass material. While the cooperative model is based on the shareholder harvesting and delivering biomass from their land, they can satisfy their contracted obligation by delivering biomass that they purchased elsewhere. This cooperative model is the basis of many of the early ethanol plants when farmers were willing to invest their own money to create a new grain market. Similar models exist for other farm products, and it is a useful strategy for projects with moderate capital costs.

The second model (Figure 3B) illustrates a balanced business model with the biomass conversion facility using an aggregator to manage the purchase, receipt, and storage of biomass with subsequent delivery to the conversion plant. This model reduces the plant's staffing and feedstock sourcing efforts, but preserves their role in processing and quality control. The aggregator's investments are limited to transportation equipment, storage site, and organizational staff to manage contracts and receipt/delivery. Harvest and initial delivery to the aggregator is the responsibility of the producer/owner. This model is useful in situations where the plant needs to maintain more control over biomass processing and quality control. For example, a cellulosic ethanol plant may use a technology that has a very narrow tolerance for changes in feedstock. In-house monitoring of feedstock may be needed to properly manage the ethanol production process.

The final model (Figure 3C) presented here features a full service aggregator. The aggregator contract with the producer/landowner for the biomass as it lies in the field. The aggregator handles all steps from harvesting until its use at the conversion facility. In this model, the landowner/producer does not participate in the biomass harvest and consequently has no capital or labor costs for biomass harvesting. It also saves the biomass producer/landowner 'the bother' of dealing with another harvesting operation and the planning effort it entails. By contracting biomass on the ground, the aggregator is likely to see a higher participation rate. However, it means that the aggregator has to invest a great deal more capital in equipment and labor to collect the material. This model saves the conversion facility from the day-to-day problems associated with the supply chain. That said, the facility must still have proper quality control oversight of their feedstock. This is an attractive model for large conversion facilities that would prefer to concentrate on their core business, be it electricity, liquid fuel, or heat production.

An assessment of the resources the different parties bring to the table often starts the decision process for developing a business structure that fits a particular biomass supply chain. For a project started by producers interested in marketing their biomass, they will likely bring the knowledge and equipment for its harvest into the process. They may want to find a business entity to convert the biomass to a value added product, such as energy, with a clear market niche. In another case, an aggregator might notice that they have a transportation network that is being under-utilized and seek a new venture to fully utilize their trucking capacity by hauling a local biomass resource.

While there are many different business structures and distributions of responsibilities, the important aspect of these relationships is that the roles of each party are understood and that they have the capabilities to carry out their portion of the supply chain. In addition to well written and understood contracts, there should be a good line of communication between all parties. It should be noted that most biomass projects will experience unplanned issues in the supply chain at some point. A team approach to solving these issues that capitalizes on the knowledge, skill, and goodwill of all the parties involved in the supply chain can resolve issues quickly and keep all business relationships intact.

4 Quality Assurance/Quality Control

Biomass is never a completely consistent product; however, most of the energy conversion technologies are designed to operate best with a consistent feedstock that remains within specified quality control parameters. Therefore, an important part of the supply chain is providing a consistent quality feedstock. Maintaining biomass quality begins when biomass is standing in the field or forest and continues until the biomass is used in the energy conversion process. Consequently, all staff in the biomass supply chain should understand quality control issues and take steps to reduce or report problems.

Moisture is probably the single most common factor to be considered in quality control. At almost all steps of the process, feedstock moisture can affect the supply chain. Although woody biomass is subject to some moisture issues, agricultural residues are much more susceptible to moisture problems. In the field, residue harvesting can be delayed for weeks until biomass is sufficiently dry for storage. Once stored, any damp biomass should be kept ventilated and protected from precipitation. In addition to degradation, increased moisture levels during storage can cause 'heating' of biomass due to microbial activity and ultimately spontaneous combustion fires (see section 5 of this chapter). In terms of using high moisture material, almost all thermochemical conversion systems are less efficient with added moisture. Energy is diverted from the conversion process to drive off (evaporate) the water in the feedstock.

Another serious quality control issue with biomass feedstocks is dirt and sand. During harvest, the material is often in contact with the ground. During the collection process for these materials, small amounts of dirt, rock, and other foreign material can be picked up. In the case of woody material, windblown dirt and sand can also become trapped in the rough bark as the tree is growing. While small amounts of foreign material will not always affect conversion technology or processing, some systems cannot tolerate dirt, sand, or other contaminants. The first place these contaminants typically cause problems is in the processing equipment that is used to resize material. Sand and dirt will increase wear rates on the cutting surfaces and material handling components of shredders, grinders, pelletizers, or briquetters. Rocks, from tiny pebbles to grapefruit sized stones, can also get into feedstocks. Small pebbles may not be noticeable in the equipment, but larger rocks can easily damage auger systems, hydraulic rams, and other moving parts.

Dirt and sand are also a large problem in the feedstock conversion process; aside from the added wear and tear on equipment, they can cause problems with the conversion chemistry. In thermo-conversion systems, minerals in the dirt and sand will turn into a 'sticky' semi-liquid or vapor under high process temperatures. The semi-liquid minerals mix with ash to form 'clinkers' at the reaction zone. These cement-like "clinkers" can plug ash handling equipment and require system shutdowns to remove. Vaporized minerals can condense and form slag on other parts of the thermo-conversion equipment. The slag will cover heat exchange surfaces and reduce efficiency, which ultimately leads to failure of components such as the boiler. In biochemical conversion processes, such as ethanol production, the sand and dirt can reduce the efficiency in conversion of cellulose to ethanol. Also microorganisms are common co-contaminates with soil particles. Some microorganisms have the potential to compete with ethanol producing microbes if the feedstock is not properly pretreated to kill the microbes. Competing microbes can sometimes use the energy from the biomass but not produce ethanol, thus reducing process efficiency.

Biomass resources supplied by industry can also have contamination issues related to the origin of the feedstock. Some of these contaminants are expected and planned for, while others are unexpected and cause significant issues. Expected contaminants would be things like creosote in railroad ties, or polyurethane on cabinet shop wastes, both of which can be handled with specific conversion technologies. However, random shipments of demolition materials with wood preservatives or cardboard waste with heavy dyes or adhesives could be problematic in a conversion technology not set up for the contamination. Unplanned contamination issues are very serious for facilities because of the environmental permitting under which a facility operates. Almost any biomass conversion unit larger than that used by a household (such as a fireplace or woodstove) falls under guidelines set by federal, state, or local pollution regulations. The guidelines will cover all emissions (air, liquid, and solid) being generated by a facility. Permits are approved based on the expected emission from a facility. If contaminants cause a facility to emit more than they are permitted, the facility can be told to scale back operations or shutdown until contamination issues are resolved. Serious long term pollution can permanently close a facility. At the same time, the entire supply chain is often shutdown to investigate both the cause of the problem and potential solutions. In the end, it is best for all parties if contamination issues can be identified early in sourcing or the supply chain, and then corrected before the energy facility has an issue.

In practical terms, once a facility is built and operational, fuel quality is probably the biggest operational issue that it will have to contend with. Even before operation, testing at startup will often reveal a need for higher quality fuel than predicted by the engineering. For this reason, all parties in the supply chain should understand their responsibilities to assure that the feedstock is delivered as specified and they should understand their liability if they deliver material that does not meet specifications. Though business relationships in rural environments often involve 'gentlemanly' agreements, which may not be well documented, feedstock quality specifications should be enshrined in written agreements and contracts before the project proceeds (see section II, chapter 3).

The best methods for assuring that all biomass falls within specifications involve quality control as a part of each step of the process. Feedstocks and the methods for handling them should be monitored for problems at the points of collection, transportation, storage, and processing. There will need to be someone responsible for formally monitoring biomass quality. Typically, both operational (efficient conversion) and regulatory (hazardous emissions) concerns mandate a trained QC staff person. In addition, the formal feedstock monitoring will verify and document whether or not contract specifications are being met and will serve as a basis for any penalties.

5 Storage

Biomass storage is a key aspect of a biomass supply chain. A properly developed storage plan can help balance issues of feedstock harvest timing, random supply shortages, delivery limitations, economic factors and safety. Due to the relatively low energy density of biomass, it takes a large volume to produce usable quantities of energy. While it would be ideal for all biomass facilities to operate on a just-in-time delivery scheme for their biomass, the reality is that biomass facilities are often using a secondary biomass stream that is available based on collection of primary 'crop'. Since there are often variations in the supplies of the secondary biomass stream, storing large volumes of biomass is often a necessity to maintain consistent biomass availability.

The use of agricultural biomass is a standard example in which biomass storage is required. Agricultural biomass is generally harvested once per year at the end of the growing season. However, energy facilities are built for year round operation. Therefore, biomass must be stockpiled for several months every year. Forestry residue may experience fluctuations as harvesting activities change throughout the season based on weather and precipitation. In all cases, measures should be taken to identify the best methods of storage to maintain quality.

A strategic reserve of biomass is often kept in storage to prevent downtime due to unpredictable supply chain issues, such as periodic crop/harvest failures or delivery interruptions. Another benefit of biomass storage is the ability to strategically purchase low cost biomass above what is immediately needed, and stockpile it for a future period when biomass is predicted to be more expensive. In these situations, economic comparisons should be made of the costs associated with storing additional feedstock with the estimated savings from having low cost biomass on hand. An important factor to consider in storage is the percentage of biomass lost due to degradation. Even with proper rotation of feedstock, biomass in the reserve pool will be lost over time due to natural decomposition. For example, 1,000 tons of wheat straw stored as a reserve may lose .5-2% by weight per month of storage. At 1% storage loss per month, 113 tons would be lost over the course of a year. A good biomass storage plan will keep the loss of material to a minimum and thus limit facility expenses.

Proper planning for biomass storage hinges on a couple of key issues, the first being storage site selection and the second being designing for daily operations. A good storage facility should be sited so that it has good transportation infrastructure for receiving and shipping or using biomass. Whether by road, rail or barge, the infrastructure must be in place to handle bulky shipments of biomass. A biomass facility producing 100 million gallons per year (MGY) of cellulosic ethanol might need upwards of 80 trucks (20 tons each) of baled agricultural residues per day. The size of the storage site is another important factor in site selection. Low density biomass requires significant square footage. In the example of the 100 MGY facility, over 300 acres of land piled with biomass to a height of 15 feet would be required to hold all the material needed for the year if brought in at fall harvest. In addition to the actual storage space, more space is needed for trucks to load/unload, space for separating batches of biomass and inspection of the facility. Space is also needed for safety reasons, which are discussed later. A conservative estimate would be that at least 50% of the site would be non-storage space.

Site selection should also factor in site terrain and hydrology. A good site should be relatively flat and allow for easily maneuvering of a variety of biomass handling equipment, which has to be on level ground while lifting material 15 to 25 feet in the air. The site must also drain water quickly so that the bottoms of feedstock piles do not become saturated with water. While it would be ideal to have a concrete pad underneath and a roof above the biomass to protect it from water and the elements, it is very expensive to engineer and construct that type of storage. The cost for a hay storage facility can exceed costs of the loss of material and quality due to weather and moisture. Therefore, most facilities with large on-site storage yards will be marginally improved lots. They may have gravel bases and paved roadways, but not enclosed storage pads. Typical improvements may be a gravel storage base, land contouring, and strategic drainage ditches located so that water can be moved away from the biomass.

Storing large amounts of biomass at a single central location may not be feasible for economic, logistical, or other reasons, in which case the biomass can be stored on the farm sites or forest harvest staging areas from which they originate. An additional option may use multiple medium sized storage sites spread throughout the collection area. Both of these options can relieve space concerns for a central facility. Multiple sites are also good for limiting traffic, noise, and debris concerns for a single large facility. Finding suitable smaller sites can also be financially or logistically easier than a large central storage site near the facility.

The operational plan is the other major key to setting up a storage site. On a day-to-day operational level, the storage plan needs to factor in receiving/shipping, weighing, equipment, labor availability, site maintenance, and weather conditions. Since these details will affect the efficiency (cost) of storage and reduce feedstock storage loss, they should be reviewed as part of supply chain development. If other nearby biomass facilities are willing to provide their insight, it is a good idea to visit their facility and ask about their experiences. They will have the best feedback on the regional issues that should be considered, including effects of weather, transportation issues, and how to work with producers to receive their material.

Safety should be a key in the daily operations plan for every storage site. Isolated biomass spread across a landscape is fairly harmless. However, feedstocks are concentrated in storage areas so their energy can be harnessed in the conversion process. Poor storage practices can lead to that concentrated energy being released prematurely as a very large and very public fire. The danger of fire comes from three general areas: unintended ignition from sparks or hot surfaces, spontaneous combustion, and intentional vandalism. The occurrence of all three of these can be greatly reduced by preventative measures.

Unintentional heat/spark fires generally result from careless practices or equipment issues. All on-site equipment should be equipped with spark arrestors and smoking should absolutely not be permitted near areas where biomass is stored. Also, all equipment should be regularly inspected and cleaned to remove biomass that can become lodged near hot engine areas. Conveyers and other machinery should be inspected and lubricated regularly to prevent bearing failure or friction that can generate heat. Processing machinery that generates dust should be properly vented and equipped with explosion resistant components. Electrical lines and lighting should be evaluated to make sure there are no opportunities for sparks from poor insulation, broken fixtures or the combustion of dust collecting on hot lighting surfaces. These basic preventative steps greatly reduce risk and are relatively inexpensive.

Spontaneous combustion fires result from the heat generated by microorganisms present in moist biomass. The moist biomass provides a food source and protection for microbes, which generate heat as part of their metabolism. The added heat promotes added microbial growth and a cycle is formed that leads to temperatures that can result in combustion. Biomass piles that are 'heating up' in their core can be opened up so that the heat will dissipate. By monitoring temperature and moisture, problems can be spotted and corrected well before a fire starts. This is a somewhat larger problem in old biomass; a proper usage rotation with the oldest feedstocks removed first will reduce risk. Another way to reduce risk is to promptly remove any biomass from the site that does not meet quality control specifications and will not be used.

While we would all like to think that no one would intentionally start a fire, it is important to realize that it can happened. Whether it's a child who is experimenting with a pack of matches or an individual who is interested in creating mischief, people need to be kept away from biomass storage sites. Proper fencing, signage, and site access control will help reduce the potential of an intentional vandalism incident. Though it is not cost effective to make a storage site into a fortress, the deterrence value of visible security will help make the majority of troublemakers think twice before entering a storage site. Depending on the location of the storage site, this may be less of a problem. Isolated rural sites are much less likely to have these issues, but potential problems should be recognized and addressed.

Most biomass storage areas will have an experience with fire if they operate for any length of time. Therefore, preventive measures should not be the only steps taken to help minimize possible damage from fire. Fire control should be an integral part of storage site planning. Steps to take vary with the site and situation; however, employee training is the first step. Employees are likely to be the first to observe and report the fire. Therefore, all employees should know how to communicate a fire to other employees and emergency responders. Their safety is also the most important concern and they should be cautioned that they are not trained (in most cases) to fight any significant fire themselves. A trained fire department should be brought in quickly to prevent the spread and damage from fire. As part of planning a storage site, it is a good idea to have a documented fire plan reviewed by the local fire department. In fact, allowing local firefighters to train for biomass fires on an isolated part of the storage site might help them if they are not familiar with bulk biomass fires. Depending on zoning and conditions, on-site water and fire hydrants should be in place to assist in putting out fires. An additional part of the fire plan should include space between storage piles. This allows for containment of fire to a portion of the stored biomass and can allow access for firefighting equipment and vehicles. Planning for this scenario can greatly reduce costs due to downtime and lost product.

Personnel safety and training should also be part of a storage site plan. It has been long recognized in agriculture and forestry that moving heavy biomass presents risks. Even being in the immediate area while large volumes of biomass are being moved has some risk. Stacking 1000-pound bales 20 feet in the air must be done with reasonable care by someone who understands how to make a ‘tight’ stack. Improper stacking can cause bales to fall, injuring workers and/or visitors. Even properly stacked biomass has risks as the face and sides of piles can collapse without warning, burying people and equipment. Proper employee training and monitoring of visitor activity greatly reduces these risks.

Another consideration in planning a storage site is the ‘good neighbor factor’. In order for a storage facility to maintain goodwill with neighbors, it is important for the facility to keep the site clean, safe, and orderly. Work on the site should include minimizing windblown biomass and promptly removing decaying or odiferous biomass. Rodents or other critters may need to be controlled if the stored biomass could be used for nesting or contains a potential food source for the pests. Depending on the area the facility is located in, it may be necessary to limit the hours of operation to keep noise down during evenings and weekends. Being a good neighbor may seem like a minor issue, but unhappy neighbors can have a big influence on permitting and licensing issues.

When thinking about biomass storage, remember that it has the biggest footprint of all the activities in a biomass energy facility. Even if the biomass is stored at multiple sites in the collection area, it is often noticeable to the community. This footprint goes beyond the physical space that the biomass occupies. People look at the biomass storage site and it influences their opinion on all of the aspects of the project and renewable energy in the broader context. At a well-managed site, this can help galvanize community support for a project. People will see the economic and community benefits for a project. At a poorly run site, they may see the project as a blight on their community and something that probably doesn't generate an economic benefit significant enough to justify its presence in their community.

6 Economic Evaluation

The last step in developing the supply chain is an economic analysis of the supply chain as a whole. While the basic economics of each step should be considered during planning for that aspect of the chain, a larger analysis should be done that can identify weaknesses in the overall model. The analysis should include scenarios in which different steps of the process end up costing more or less than originally budgeted. The data can be used to re-evaluate parts of the supply chain before money is invested. It can also be used as a guide once the supply chain is operational to help contain costs if there are problems.

The overall economic analysis will probably be more difficult to do when more than one party is involved in supply chain operation. Individuals and businesses may be reluctant to share cost and revenue data. However, there needs to be a broad look at economic and financial risks in these situations. Making certain that all parties will be financially stable is a key to making the supply chain sustainable.

7 Summary

Establishing a biomass supply chain is fairly simple in concept. However, there are many details that must be accounted for to make the feedstock supply chain work as an efficient system. Since each situation is unique, supply chain development needs to be based on the conditions for the individual facility or market the biomass will supply. The common elements that apply to developing successful supply chains are that they are using sustainable volumes of bulky biomass and that the biomass is brought to the conversion facility at an economically feasible cost. Proper project planning and operations are needed to make sure these elements are part of any new supply chain and will help contribute to a successful biomass to energy project.

8 Tables & Graphs

Table 1. Wide Variety of Potential Biomass Energy Feedstocks

Municipal Resources

- Newspaper
- MSW (municipal solid waste [garbage])
- Sewage Sludge

Industrial By-products

- Cardboard
- Carpentry/Wood Scrap
- Fish Canning Plant Waste

Agricultural Biomass

- Agricultural Residues
  - Wheat Straw
  - Orange Peels
- Biomass Cropping
  - Switchgrass
  - Miscanthus
  - Elephant Grass
- Other
  - Turkey Litter

Forestry

- Timber/Woodlands
  - Wood Chips
  - Slash
- Agro-Forestry
  - Willow Coppice
  - Hybrid Poplar

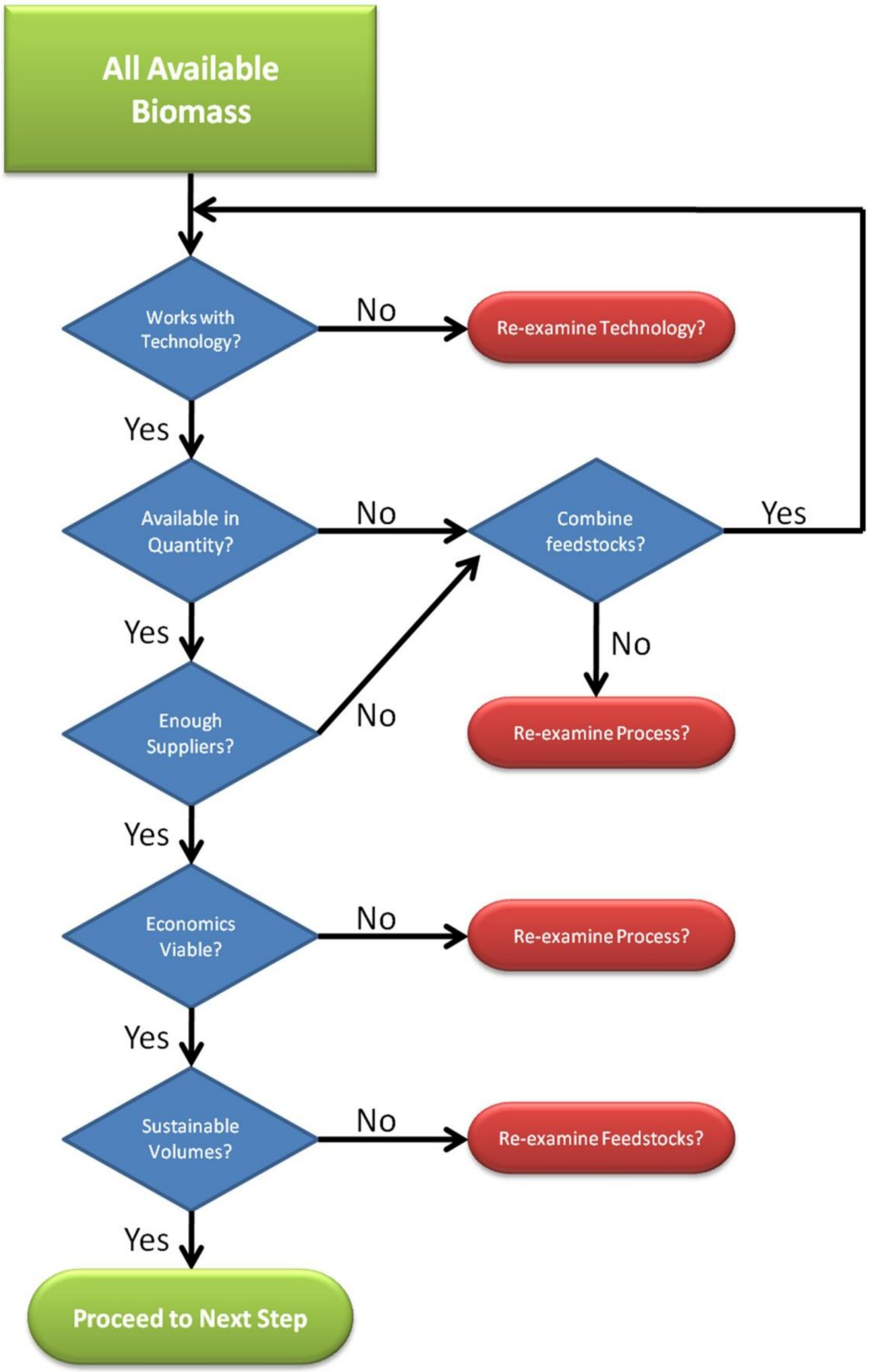

Figure 1. Feedstock Supply Decision Tree
This decision pathway presents some of the questions that should be asked to verify a particular feedstock fits the needs for a particular conversion technology and a particular scale.

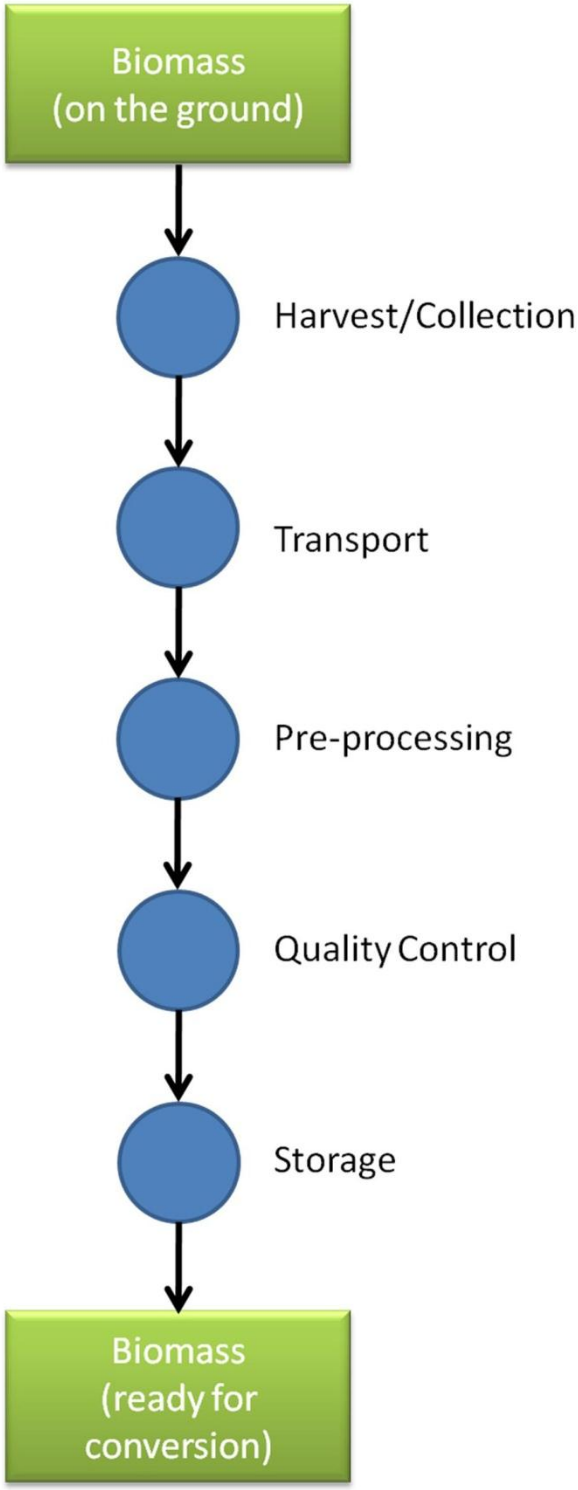

Figure 2 Overview of Steps in Supply Chain
This diagram highlights the major points needed for a biomass supply chain.

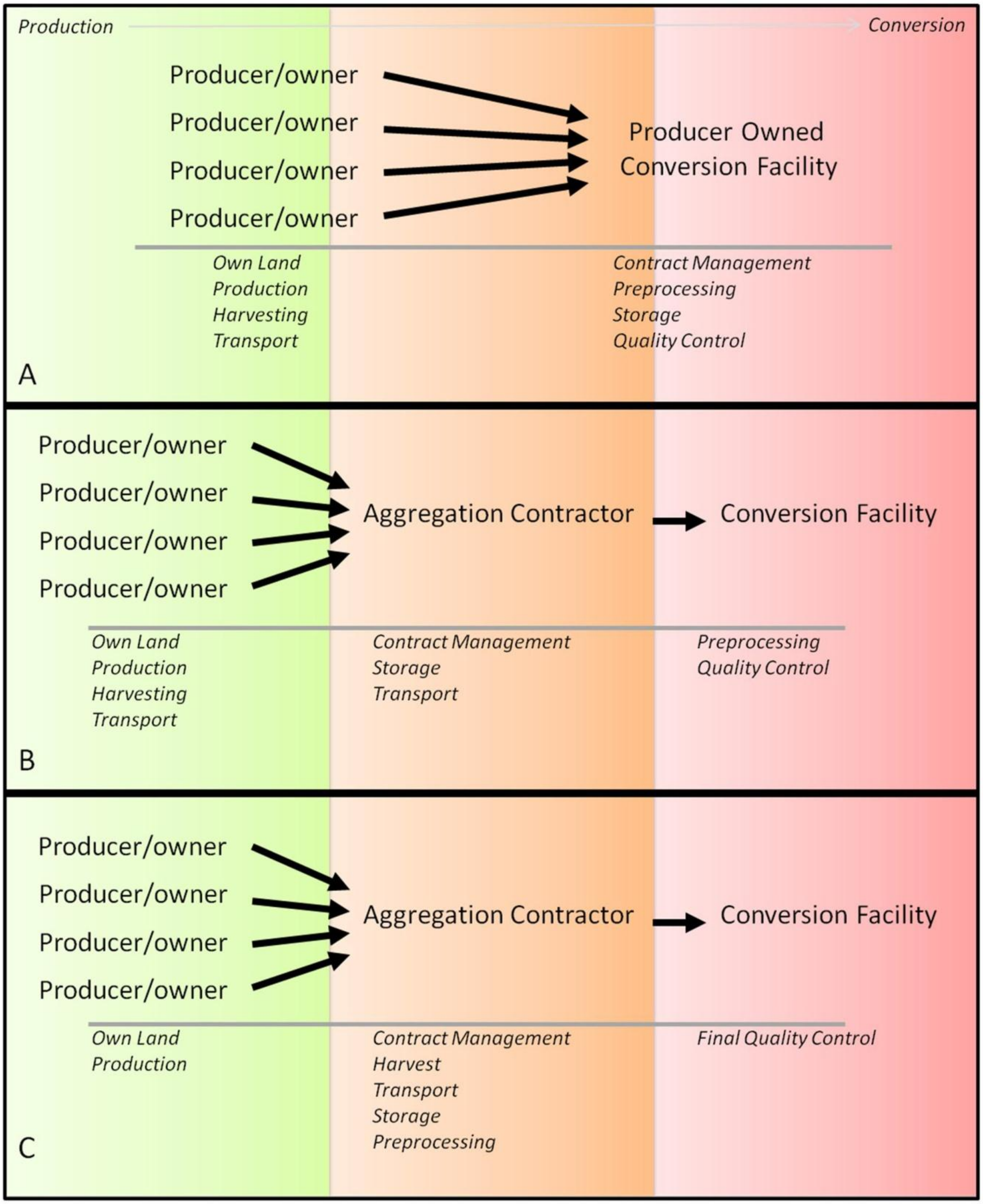

Figure 3. Potential Models of Biomass Supply Chains