UTILIZING QUALITY FUNCTION DEPLOYMENT TO CREATE A QUALITY REQUIREMENT MATRIX FOR BIOFUEL REFINERY INPUTS VIA VOICE OF CUSTOMER TECHNIQUES

By

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LIST OF ABBREVIATIONS AND ACRONYMS

AFRI .... Agriculture and Food Research Initiative
ARRA .... American Recovery and Reinvestment Act
ASQ .... American Society for Quality
BMP .... Best Management Practice
BRDB .... Biomass Research and Development Board
BRDI .... Biomass Research and Development Initiative
CTS .... Critical-to-Satisfaction
DOE .... Department of Energy
EERE .... Energy Efficiency and Renewable Energy
FASE .... Food and Agricultural Science Enhancement
FMEA .... Failure Mode and Effects Analysis
HOQ .... House of Quality
INL .... Idaho National Laboratory
IBRF .... Integrated Biorefinery Research Facility
NABC .... National Advanced Biofuels Consortium
NIFA .... National Institute of Food and Agriculture
NREL .... National Renewable Energy Laboratory
NRI .... National Research Initiative
OSU .... Oklahoma State University
PNL .... Pacific Northwest Laboratory
QFD .... Quality Function Deployment
R&D .... Research and Development
RD&D .... Research, Development, and Deployment
RFA .... Renewable Fuels Association
RFS .... Renewable Fuel Standard
USDA .... United States Department of Agriculture
VOC .... Voice of the Customer

CHAPTER I

DEVELOPMENT OF A QUALITY FUNCTION DEPLOYMENT MATRIX FOR BIOFUEL REFINERY REQUIREMENTS

ABSTRACT

There is currently no useful method in place for researchers to determine what qualities of biomass the ethanol refineries desire. However, an industrial engineering quality tool typically used in new product development, Quality Function Deployment (QFD), could be adapted to the biomass supply situation. This tool will be applied to an input supply system specifically for production of advanced biofuels from biomass feedstocks to determine desired qualities of biomass and provide the best product to the refineries. This requires gathering and analyzing the Voice of the Customer (VOC) from biomass conversion experts and constructing a House of Quality (HOQ) that details the qualities desired by those customers in order to propose engineering measures for satisfying those requirements. Quality Function Deployment will be demonstrated as a quality tool that can be applied towards a supply process within agricultural engineering.

The adapted tool could be used by biomass producers to solicit the qualities desired by biorefineries and develop engineering specifications to work towards. It could also be

used by the biofuel production facility to define and rank the required qualities of biomass and create product specifications that the facility could provide to the supplier to ensure a consistent high-quality supply. Implementation of such a method would also create a research tool to supplement research proposals to help ensure that the project addresses the specific areas of concern to those affected by the research results.

This study shows that QFD can be successfully applied to the biofuel supply system and gives the process for carrying out the analysis.

INTRODUCTION

Demands for petroleum and fossil fuel-based energy continue to grow with rising world populations and the continuing development of nations on the world stage. The Energy Independence and Security Act of 2007 set the Renewable Fuel Standard (RFS) which mandates that 36 billion gallons of biofuels be produced in the United States by 2022, with corn ethanol limited to 15 billion gallons (Sissine, 2007). Of the 36 billion gallons, 16 billion gallons must be produced from cellulosic feedstocks. One of the positive aspects of using cellulosic crops for bioenergy is the ability to use existing harvesting equipment that is readily available. One of the challenges to establishing the cellulosic biofuels industry is maintaining the economic and ecological sustainability of current supply system infrastructures while continuously providing production facilities with the required quantities and desired qualities of resources (Hess et al, 2009). This challenge is being addressed by researchers across the country.

The research can be based on what the researchers think and conclude given past experiences. It may be based upon industry trends or government direction, but does it always accurately address the needs of the end user? Focus must be on what is important to the "customer", that is, the one who is affected by the research. In the case of an ethanol production facility, it is critical that the biorefineries receive high-quality inputs, as biomass requirements are estimated at roughly 250 million tons by 2017 and could grow to as much as 700 million tons by 2025 (Fales et al, 2007).

Research continues at Oklahoma State University (OSU) and at institutions throughout the country to develop technically and economically viable alternatives to petroleum-based fuels. Some best management practices (BMPs) are being developed in the areas of stand establishment, nutrient management, harvesting, and storage (OSU, 2009). One area of research that will affect the quality of the biomass being delivered to the production facility is storage. In order for a biorefinery to maintain a continuous operation, the biomass will undoubtedly need to be stored for a period of time before it is used by the ethanol production facility. This could be covered or uncovered storage, take place at the field or at the refinery, and last for a short period of time or up to a year. This is only one example as other research opportunities for biomass production might include cutting and conditioning, raking for dry-down, baling and further packing the material, and transporting the biomass to the biorefinery.

With so many research opportunities available, there will be some that are very important, some that matter to an extent, and some that are less significant. The problem is, which opportunities fall into each of these categories? How do researchers know as they approach these topics? While it is fair to estimate that researchers, practitioners, and other stakeholders have influence over these areas, it is ultimately the end users of the product that can say what they desire. For a biomass-to-fuel supply system, this may be based on a specific conversion process, the nature of biomass, and industry trends. But without capturing this information and knowing for sure, research could be undertaken currently that does not have a significant effect on the process, or significant factors could be overlooked.

Conducting research to supply biomass qualities that do not address the needs of the ethanol production facility is an impractical undertaking, just as designing a product with features that the customers do not care for is also a waste of time and resources. Quality Function Deployment (QFD) was created to capture the requirements set forth by the end user (or customer) and use them to develop a product with greater value that would increase customer satisfaction. It is a tool that captures, analyzes, and implements the desired characteristics through Voice of the Customer (VOC) analysis and construction of a House of Quality (HOQ).

BACKGROUND

Quality Function Deployment Basics

History and Purpose

To create a product that satisfied the customer's needs and the benefits they sought, Quality Function Deployment was established as a tool to meet product development objectives that focus on the customer or user. Yoji Akao first proposed the idea of quality deployment in 1966. He described quality deployment as a system in April 1972 with the name “Hinshitsu Tenkai System”, which translates as “Quality Deployment System” (Revelle, et al, 1998). In May 1972 Mitsubishi Heavy Industry proposed a Quality Table to aid in designing supertankers for its Kobe Shipyards. The term "quality house" (seen today as the House of Quality) was first presented in 1979 by Toyota Auto Body at a Japanese standards conference. QFD was introduced in the United States in 1983 by Akao and others at a seminar for quality managers from top U.S. companies. Ford Motor Company was one of the first companies interested in developing and deploying QFD in the U.S. Other auto makers began evolving their processes to include the use of QFD after they saw the successes Japanese auto companies were achieving with it. Throughout the late 1980's, publications by Bob King, John Hauser, and Don Clausing further spread QFD methodology throughout the United States (Revelle, et al, 1998).

The objectives of QFD include translating the customer desires into product quality characteristics and design requirements and ensuring that those qualities are checked prior to and throughout the design process. In a supply-chain, this is equivalent to ensuring that the customer receives the correct product with the quality demanded. For a biomass-to-refinery supply system, this guarantees that the refinery has a quality feedstock supply to efficiently convert to biofuels or other bio-based products.

QFD was originally used for creating products but has grown to see use in providing services to customers as well. It is used to develop ways to meet the needs of the customer and analyze them in further detail. QFD, simply stated, is a means for translating customer input into product or service outputs. In competition, such as that where auto makers are vying for car buyers to purchase their products, QFD helps to exceed customers' expectations, giving them amenities they may not have realized they wanted or could have. The QFD analysis is based upon deploying the qualities a customer desires throughout an entire product development cycle, or throughout an entire company.

Benefits and Challenges

The process facilitates efforts among engineering, marketing, and manufacturing divisions of a company during product design and development. Engineers summarize customer requirements and engineering performance information for use during design and manufacturing; marketing gathers the summary to reach customers later on; and management can use the summary and product information to make strategic decisions (Shillito, 1994). QFD is not only a quality tool, but also a planning process used for customer-based products, services, processes, and the like. It can therefore be extended beyond traditional design processes to the supplier industry.

Instead of relying on product developers to supply all of the product specifications, QFD utilizing VOC empowers the customer to provide product needs and wants that can then be translated into technical objectives. Instead of being a reactive cause and effect analysis during and after product design as Failure Mode and Effects Analysis (FMEA) can be, QFD focuses on being proactive and contributing valuable information before important decisions are made. Like FMEA, however, QFD requires more resources to be allocated earlier in the product development process but requires fewer resources over time. Figure 1.1 illustrates this concept, which can be applied to the biomass supply model: if resources are allocated up front to determine what qualities of biomass the refineries need and want, fewer resources may be needed to produce those qualities, as research will not be directed towards unnecessary objectives.

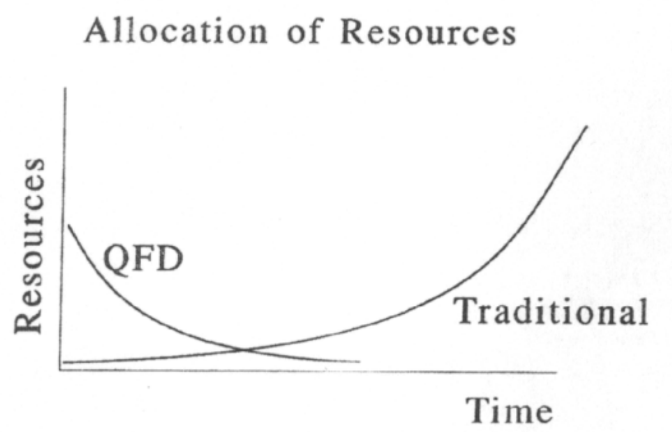

Figure 1.1. QFD Comparison of Resource Allocation (Terninko, 1997)

QFD is important early in the planning process as it helps define which details require the most focus, as well as which details may require the most resources or be most difficult to achieve. QFD is not a one-time process, but it requires iterations to gather, organize, display, and reorganize information as it becomes available. This evolving methodology produces outcomes that are more closely aligned with what the customer desires.

There are several benefits to using Quality Function Deployment (Terninko, 1997 and Revelle et al, 1998). QFD:

- Improves product development by soliciting the customers' requirements in order to more accurately define the product requirements.
- Provides direction to the design or development process through guided steps that reflect what is needed to satisfy each customer requirement.

- Increases customer satisfaction.
- Allows an organization to allocate resources more effectively and efficiency.
- Reduces product introduction costs.
- Shortens duration of development by 2-3 times.
- Reduces engineering changes 2-4 times.
- Improves product manufacturability.
- Facilitates communication and cooperation throughout the organization.
- Creates common language/definitions for the product.
- Develops a product reference for future use.
- Other benefits of QFD include lower costs, reduced time requirements, early determination of requirements and high-risk areas, efficient use of resources, and reduction of late changes.

To illustrate how QFD can help shorten time requirements, consider Figures 1.2 and 1.3 below. Figure 1.2 illustrates the flow of a traditional sequential product design in which one activity must finish before the next one can begin. If there is a problem with, for example, the ability to manufacture the product as designed, the product development team must go backwards to alter the design and then proceed through the steps again.

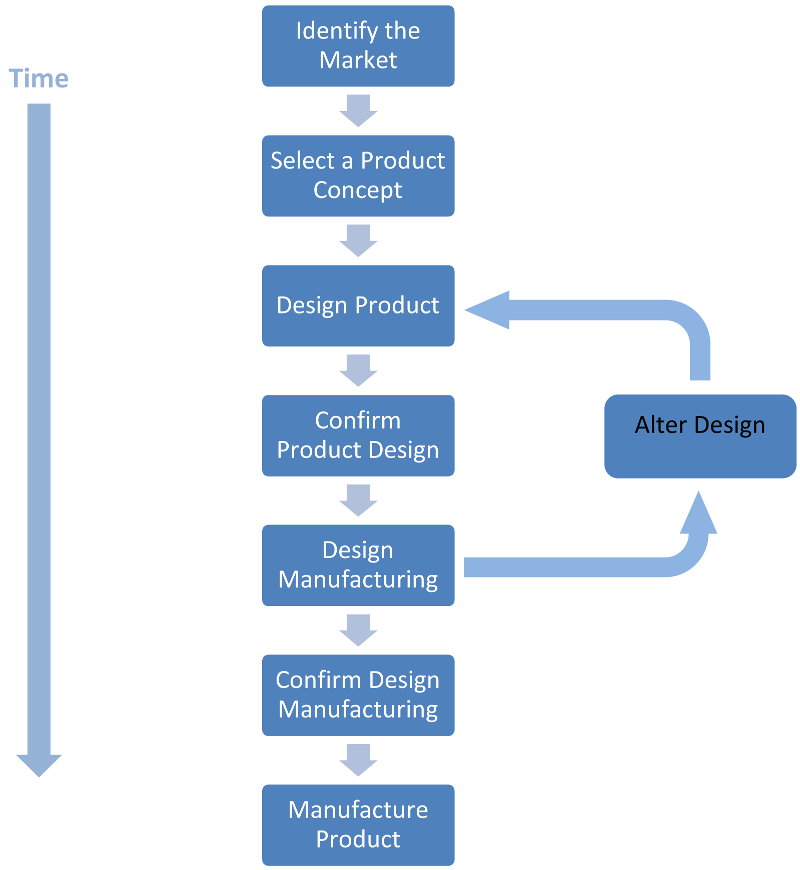

Figure 1.2. Example of a Sequential Design Flowchart

Concurrent design reduces the time requirements by “compressing” the activities on the flowchart. Activities take place concurrently, with each having a start time “staggered” with the ones before and after it as shown in Figure 1.3. A cross-functional team, a necessary component of QFD, is required for concurrent design to succeed. Effective communication becomes an instrumental tool which can lead to fewer design changes and reduced costs. For instance, manufacturing participates in the early design process.

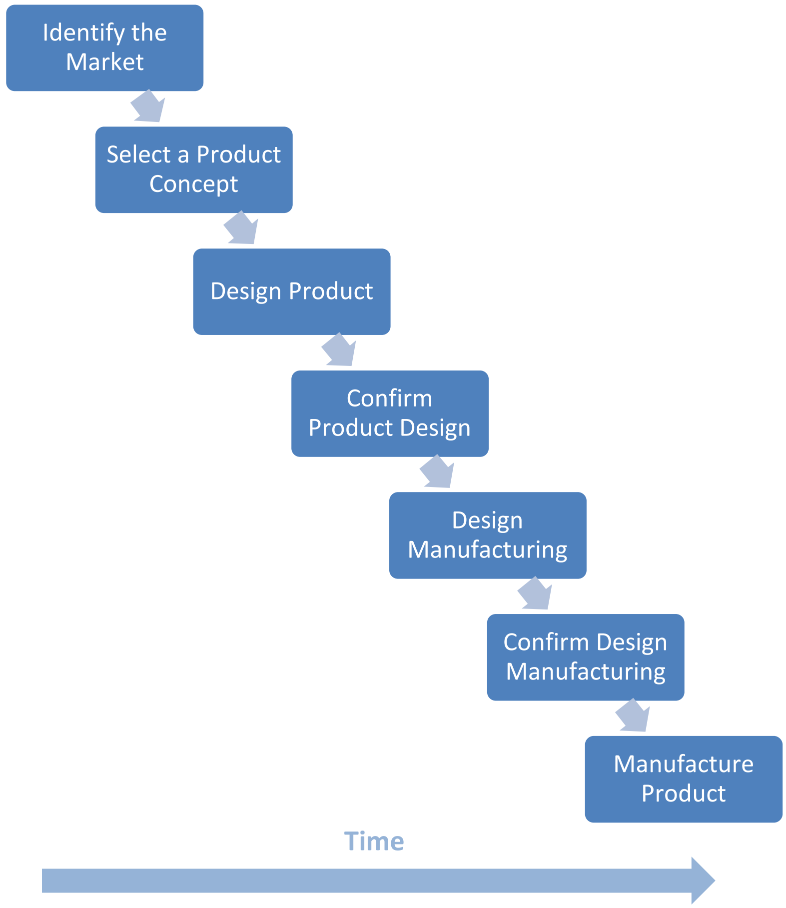

Figure 1.3. Example of a Concurrent Design Flowchart

One key to a successful implementation of QFD is flexibility and creativeness. The exact format of one HOQ and QFD analysis may likely not fit others. Instead, the basic format and guidelines can be expanded and reworked for each individual problem as necessary. Likewise, the design flowcharts in Figures 1.2 and 1.3 can be reworded for the specific customer base. Figure 1.4 shows the concurrent flowchart redesigned into a relevant process for the biomass feedstock supplier.

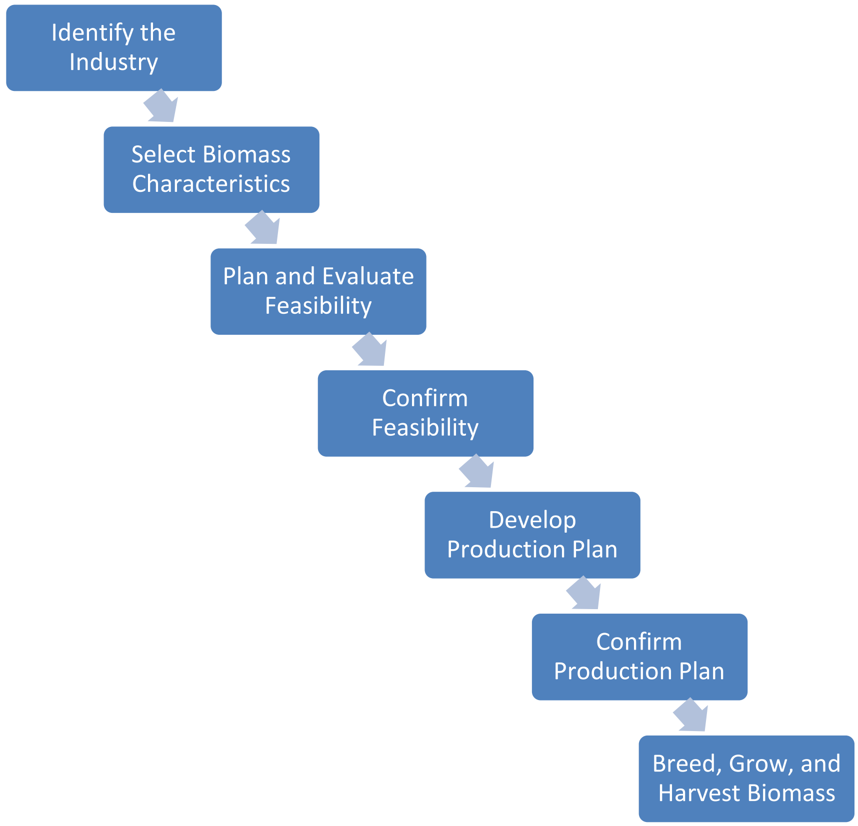

Figure 1.4. Concurrent Process Flowchart for Biomass Feedstock Supply

Ease of integration is another benefit of QFD, which supports other quality programs by identifying goals early in the process and organizing and prioritizing key requirements/characteristics.

Additionally, QFD identifies negative correlations between different methods of achieving what the customer desires. This often includes physical contradictions. For example, a customer may want to buy a car that has a large interior, fast acceleration, and low fuel consumption. But as vehicle size and engine performance increases, fuel efficiency tends to decrease. The downfall is that QFD does not propose any solutions to these negative correlations, and the methods implemented typically involve compromise. Relative to the biomass supply system, imagine that an ethanol producer wants the feedstock to be delivered with 30-50% moisture content so that less water has to be added to the process later on. At the same time, the producer wants to pay less in transportation costs, so little to no moisture in the biomass equates to more material being brought in on each truck. In circumstances such as these, mathematical models and what-if analyses may be used to find the best solution.

QFD is not a cut-and-dry solution to every problem, and the strengths and weaknesses must be understood before deploying the methodology. Some of these are outlined briefly below.

Strengths:

- It is a structured process.
- Most planning is up-front which leads to lower costs since most changes are made early, which also decreases production time.
- Resources can be used more efficiently.
- Requirements and high-risk areas are identified and can be addressed early on.
- Product or service is better developed to meet the needs of the customer, resulting in fewer complaints, returns, and warranty claims, and most importantly greater customer satisfaction.
- For a biorefinery, the biomass inputs can closely match what the refinery desires; processes can be optimized to be more efficient.

Weaknesses:

- Requires understanding of the QFD method and a commitment from those involved to stay with the QFD plan.
- Requires more up-front planning (the trade-off for less development time).
- Delays in the design cycle can be difficult or impossible to navigate.
- For a biorefinery, since the technology and processes have not yet matured, some concepts might be overlooked.

Additionally, Shillito outlines a series of limitations that should be kept in mind before conducting a QFD analysis (1994):

- The QFD cannot be immediately started with construction of the HOQ.
- New teams can easily waste time, avoid decisions, and attempt to prematurely solve problems.
- Individuals on the team have other commitments that distract them from the QFD program.
- The QFD team cannot brainstorm customer needs; the customers must provide their needs to the team.
- The QFD team cannot be expected to agree on every detail of the context of the VOC.
- A group with a poor or nonexistent scope or purpose cannot be expected to create one on their own.
- Undocumented assumptions can derail team progress.

- Individuals cannot be thrown together as a team and be expected to have the same vision for the product or service.

To overcome these limits, a team leader must facilitate the QFD process by creating the scope for the team, guiding their focus, and facilitating productive discussions throughout the entire project. The QFD leader should be versed in the process and understand its capabilities and the difficulties that can arise so that the team can avoid pitfalls and mistakes commonly made by QFD teams as described by Shillito (1994) and Terninko (1997):

- The team attempts to create too large of a matrix or too many matrices.
- The team mixes the customer's needs with quick technical solutions as opposed to pausing and responding to the Voice of the Customer.
- The purpose of the QFD study is not clear.
- The final decision maker is not obvious.
- Management may issue resources for a QFD project hoping for quick results.
- QFD may be implemented too late in the product design cycle.
- Shortcuts are taken to implement QFD quickly, and the results are unsuccessful or inconsistent.

When the benefits of QFD are accepted, the strengths and weaknesses are clearly defined, the limitations are understood, and common mistakes and pitfalls are identified, the QFD team can maximize its impact. In addition, Shillito describes qualities of successful QFD teams (1994):

- The team and the customers understand that there are potential advantages of using QFD and that it is not just another fad or buzzword.
- They see the QFD process as low-stress and being compatible with the current processes.
- They are given clear goals and a well-defined direction.
- They are able to work without distractive interference.
- They can freely access the required data.
- They take full responsibility for the deliverables.
- They balance rational thinking and intuitiveness.

The first step in QFD is to understand the customer by determining characteristics and background of the customer. The second step in QFD is obtaining the Voice of the Customer by directly receiving the customer's needs and understanding the context in which they are given. It is important to develop an understanding of the subjective and objective requirements of the customer so they can be translated into performance measures. A performance measure is a technical evaluation that measures the product's performance given a quality demanded by the customer. This involves translating customer statements into objective engineering requirements. The third step prioritizes the customer's requirements and then translates them into workable (typically engineering) objectives and performance measures. It is during this step that the QFD matrix known as the HOQ takes shape.

A variation of QFD may save time and training by following the Pareto principle and applying it to the most highly prioritized customer needs. This still involves understanding and obtaining the Voice of the Customer, organizing their needs, and developing a consensus as to the most important characteristics which can then be prioritized. But by focusing on the top 20% of the most important needs, the Pareto principle suggests that 80% of the quality requirements will be addressed.

Finding the Voice of the Customer

Voice of the Customer Basics

The QFD methodology uses the Voice of the Customer approach to obtain, organize, and prioritize customer-based inputs. VOC techniques are used to improve a design, process, or performance; to develop a business plan; and to satisfy unmet needs of a customer. The Voice of the Customer is the collection of attributes, requirements, and demanded quality as described by the customer. In the case of biorefinery inputs, the VOC is the compilation of characteristics of the feedstock inputs the processors wish to see.

Gathering the Voice of the Customer is usually a continuous process which may involve direct interviews, round table discussions, focus groups, and brainstorming. Essentially, the VOC describes how the customer wants a product to function, such as “easy to carry”, “does not leak”, “requires little maintenance”, or in our case, “converts easily.” This should not be confused with product features, which are the design requirements and engineering attributes, such as “weighs less than 20 pounds”, “requires 12 N of force to open”, “provides an air-tight seal”, or for our example, “contains less than 20% lignin.” Voice of the Customer analysis is a process of understanding customer preferences and capturing and analyzing details about a customer's requirements and desires in a product. It provides an in-depth understanding of product requirements as given by the customer. The key to an effective VOC analysis is actually listening to the customer and implementing what is learned. Customers generally know the basic utility they are looking for in a product and are often open to sharing those opinions with companies in order to create a better product, which is the purpose of implementing VOC.

Utility is directly related to customer satisfaction. Different levels of utility a product has fulfill corresponding levels of satisfaction for the customer. The Kano model of satisfaction in Figure 1.5 shows three basic customer measures. Basic requirements are those that the customer cannot do without. They are assumed by the customer and will not typically be brought up unless they are missing, i.e. things that "go without saying." For example, you would expect a car to have a seat, wheels and tires, and foot pedals. Performance measures are those that the customer would like to see and will probably scrutinize when comparing products from different companies. These are features given by the VOC and are generally what a customer thinks about when purchasing a product. Performance comparisons often come from market research and product benchmarking. A company can take advantage by having the best performance quality or by improving upon what other companies cannot seem to do well. Often benchmarking will reveal an area that no one is able to do extremely well in; this can provide a great opportunity to give the customers a level of performance they are not used to having. Excitement measures are those that the customer did not even know they wanted but are impressed by when they use them. They are features that move technologies to the next level and have the "wow" factor that customers did not expect.

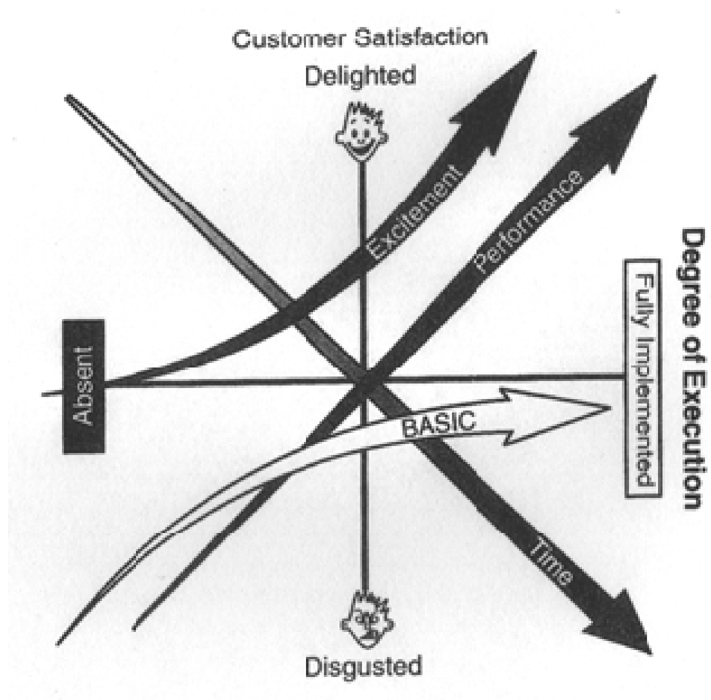

Figure 1.5. Kano Model of Customer Satisfaction (Revelle et al, 1998)

When designing an input supply system, it is helpful to view it as a customer-driven product. The input supply is the product that the customer will utilize, and the goal is to achieve a high level of customer satisfaction. The bioenergy feedstock supply system then follows the same principles of customer satisfaction outlined in the Kano Model.

Assume a customer wants to perform a task (biofuel conversion) with the inputs supplied. This task will be accomplished through the functions of the inputs; the reason the product exists. The functions can be analyzed in terms of work functions (what are the basic required tasks the product must perform), sell functions (what performance does this product offer that makes it desirable), and perk functions (what unexpected aspects excite the user and make it even more attractive) (Shillito, 2001). Knowing what qualities to offer in the biomass supply determine how desirable the biomass is to the biorefinery and can be captured through Voice of the Customer analysis.

Yang outlines why it is important to capture and analyze VOC information (2008):

- Accurate and sufficient information from the customer is required to develop inputs to product design and manufacturing processes at the system, subsystem, and component levels.
- A quality set of VOC information shows what the basic utility, performance, and excitement factors are.
- Voice of the Customer information is a necessity for decision making.
- Capturing the Voice of the Customer can often reveal where improvements can be limited in scope and not require complete redesign.

Two very important perceptions customers have include and value and quality. Customer value is the utility, performance, and excitement that the customer perceives. It consists of those key attributes that define a customer's satisfaction and appreciation of a product or service. This information can only be derived from the VOC. While quality is defined as "the characteristics of a product or service that bear on its ability to satisfy stated or implied needs" (ASQ), the satisfaction a customer has for a product or service's quality is subjective. Quality can be considered one of the values a customer has for a product or service and therefore is derived from VOC information. Qualitative information is descriptive, subjective and exploratory. It tends to be open-ended but can often help bring relationships and context to the surface.

Benefits of a product or service help define the customer's value. Customers often use statements in VOC surveys to describe additional benefits they would like to experience. Customers might give descriptions involving words such as "better", "faster", "safer", "more durable" or "easier to use". These statements do not offer precise descriptions of function. Qualifying descriptors would list jobs to be performed, desired outcomes, and constraints. Value can be express quantitatively using ranking and weights (numbers) or specific descriptors (attributes) that give the data objective meaning.

Identifying the Customer

How does one identify the customer and persuade an individual that it is worth their time to participate in a VOC study? First off, they must have a deep interest in the subject at hand - both the problem and any solutions that may arise. Those with knowledge and expertise in that subject would have reached that point because of a genuine interest and should therefore be considered as qualified participants. The selected respondents must not only have an interest in the problem, they must have high motivation to be a part of the solution. It is up to the interviewing group to communicate the importance of its objectives and the importance of the participant in contributing to the process. Also, the respondents should clearly understand their roles and obligations so that no surprises arise later on that would lessen their motivations. Finally, the respondents should understand that their contributions are well-appreciated and will be used effectively. Communicating the importance of gathering the VOC and how it will benefit the customer is as critical as the method itself.

Collecting the Customer's Voice

There are several research techniques that can be considered to collect customer evaluations of a product:

1. Observe customers buying the product
2. Observe customers using the product
3. Examine product after usage
4. Talk to customers at gatherings (shows, conventions, meetings)
5. Customer focus groups and one-on-one interviews

Delphi Technique – Interview questions are a common way of collecting VOC data because the information gathered comes directly from the customer and is analyzed in steps. One method of interviewing customer is the Delphi technique, a collection method that does not require participants to meet directly and at the same time, such as with group interaction, phone conference, or web meetings. The objective of using the Delphi technique is to aggregate the opinions of several individuals to provide the questioning team with a stronger basis for effective decision-making (Delbecq, 1975). The technique seeks to identify possible program alternatives, explore underlying assumptions that influence judgments, derive a consensus, correlate information gathered, and educate the respondents on the complexities of the subject.

The Delphi method uses a series of carefully designed questionnaires to solicit feedback and opinions from those in the study. Once the respondent group is identified, the initial questionnaire is developed and distributed. With the Delphi technique, respondents generate ideas and opinions independently of each other. Respondents are isolated and can contribute free from evaluation or criticism of others while knowing their responses will only be handled by the questioning team. The individuals' responses are pooled during the analysis and may be used to generate a second set of questions. This second questionnaire typically contains information gathered from the first round of responses asks the respondents to further evaluate those ideas. This involves quantitative analysis which may include ranking items, elaborating on a particular area, or giving a yes/no vote on a particular idea so that an understanding of priorities begins to emerge. These questionnaires are returned and once again summarized and analyzed. Typically, the second questionnaire identifies areas of agreement and disagreement between respondents. It also further elaborates on topics requiring clarification.

There are several advantages to using the Delphi technique.

- It keeps responses anonymous while preventing one individual from dominating the process.
- Subject matter experts are typically spread throughout a state, country, or the world. Delphi allows equal solicitation of ideas from the individuals.
- Isolating the responses and providing detailed questions to think through allows for innovative ideas to surface, but it can also give rise to incomplete or conflicting ideas as well.
- When the ideas are effectively pooled together, conclusions can be drawn to form an overview of the subject while including individuals who would otherwise be unable to contribute at the same level.
- The respondents are allowed to participate freely without competition or status pressure.

- By avoiding travel, providing flexibility in response time, and keeping anonymity of the respondents, the Delphi technique better serves those participating in the study (Delbecq, 1975).

Asking the Right Questions

When developing VOC questions, it is important to determine what benefits the customer will value. Features that are not linked to customer benefits are not value-added, they are cost-added. Roman provides tips for creating survey questions (2011):

• Demonstrate a commitment to provide value to the customer. Customers are more likely to provide information if they are convinced that benefits will arise from it, including personal service, lower costs, and more relevant uses.

• Define the specific issues clearly.

• Develop a set of research objectives for these issues.

• Do not define objectives too broadly; focus on the primary issues that can improve the customer's experience.

• Keep the number of objectives small enough to manage; too many objectives will create too many questions which will dilute the in-depth understanding of these discussions.

• Create questions that challenge and engage respondents.

What customers say and how they say it is highly dependent on the questions they are asked: what the questions ask for and how they are structured. Although open-ended questions may be useful for finding areas of interest that were not considered when developing the survey, closed, specific questions allow the customer to provide specific direction. Therefore, it is important to identify what specific information is needed from each customer. For product development, questions should be asked that derive functional requirements and design parameters. For service providers, questions should obtain customer ratings and evaluations.

Analyzing the Voice of the Customer

Analyzing the voice of the customer occurs in steps. First, the customers' responses must be recorded verbatim. Using VOC allows customers to give information in their own words which will often provide better feedback with an overall view of the product or service. The challenge is that initial VOC information is typically vague and disorganized. The raw VOC must be translated into tangible product information in the form of product design or supply input terms. This can be done by asking, why? If a customer says the product is difficult to use, ask why that is, and write it in terms of the design of the product. If a customer says the input does not provide high enough quality, ask why that is, and write it in terms of the supply. The objective is to get the customer comments into a format that relates to the product in a way that can be measured, verified, or ranked in order to establish a clearer picture of what the customer actually wants and requires. This format relates performance and standards requirements for the user that are not merely descriptive, such as "faster acceleration", but precise in their definition, such as "accelerates from 0-60 mph in eight seconds or less."

When analyzing customer comments, there are several guidelines that can be followed to ensure the best translation of the VOC. Statements should have a simple definition, covering only one concept at a time. Statements should include tangible, concrete information; descriptions that cannot be quantified should be avoided (Shillito, 2001). Finally, statements should describe the requirements and avoid attempts to solve the problem by providing requirements or extraneous detail.

The VOC research technique can be used to validate or nullify previous assumptions, as can be seen in the following case study. In product development, this helps to eliminate unnecessary expenses and reduce unwanted features. For large research programs, it has the potential to sort out where money should be spent and what research topics are less relevant.

Voice of the Customer Case Study: MSC Industrial Direct

MSC Industrial Direct was founded in 1941 and distributes metalworking, maintenance, and repair and operations (MRO) industrial supplies with a product offering exceeding 600,000 (Roman, 2011). MSC is affected by the changing market and was significantly impacted by the economic downturn that began in 2008. A specific customer base that MSC served changed their purchasing habits which presented a new challenge for MSC to effectively serve them.

Because MSC is customer-focused, the company stays close to its customers and solicits and captures customer feedback to ensure that every customer is served. Although it realized the change in customer behavior would be easy to explain away by stating that the recession caused customers to purchase fewer products, this did not hold true for the other customer segments in which purchasing behavior did not change. For MSC, the new challenge focused on a certain significant customer group. MSC approached the problem by assuming that it didn't know the answer to any questions it would ask of this customer base.

MSC started by defining a clear and concise set of research objectives targeted at this customer segment. Initial quantitative surveys indicated that the customer segment was satisfied with MSC, it product offerings, and its prices. With consultation from Ernan Roman, MSC set out to determine:

- Impacts the slowing economy had on spending,
- Factors that determine what the customer buys,
- Factors that determine when the customer buys,
- Factors that determine from whom the customer buys, and
- If there is any supplier that receives the bulk of the customer's orders, and if so, why that occurs.

These objectives became important business questions the customer segment would benefit from answering. The next step for MSC, however, was identifying which customers within that segment to sample. Once the sample of customers was selected, the objectives had to be translated into research questions. To form specific, engaging questions, MSC built a cross-functional team made up of individuals from sales, marketing, advertising, logistics, customer service, and e-commerce. The sales team took the earliest lead in the process since that team is in closest contact to MSC's customers. To understand both the depth and strength of the customers' responses, qualitative and quantitative questions were developed into an Interview Guide (Roman, 2011). It is important to note that this Interview Guide was not strictly a checklist, but also a template for further conversation.

Research revealed that MSC was not losing customers or even making fewer total sales necessarily, but rather that customer purchasing habits changed and customers tended to make larger purchases, but they made those purchases less frequently. It also validated that MSC's values and services were consistent with what the particular customer segment wanted. The VOC research kept MSC from spending unnecessary time and resources trying to win back customers who had not actually left but had just changed their buying habits. It also revealed ways in which MSC could better service its customers given the new patterns in purchasing behavior.

Building a House of Quality

Once VOC information has been captured and the requirements analyzed, a customer requirements matrix or House of Quality is constructed. Figure 1.6 shows a typical HOQ and the basic information generally found within it.

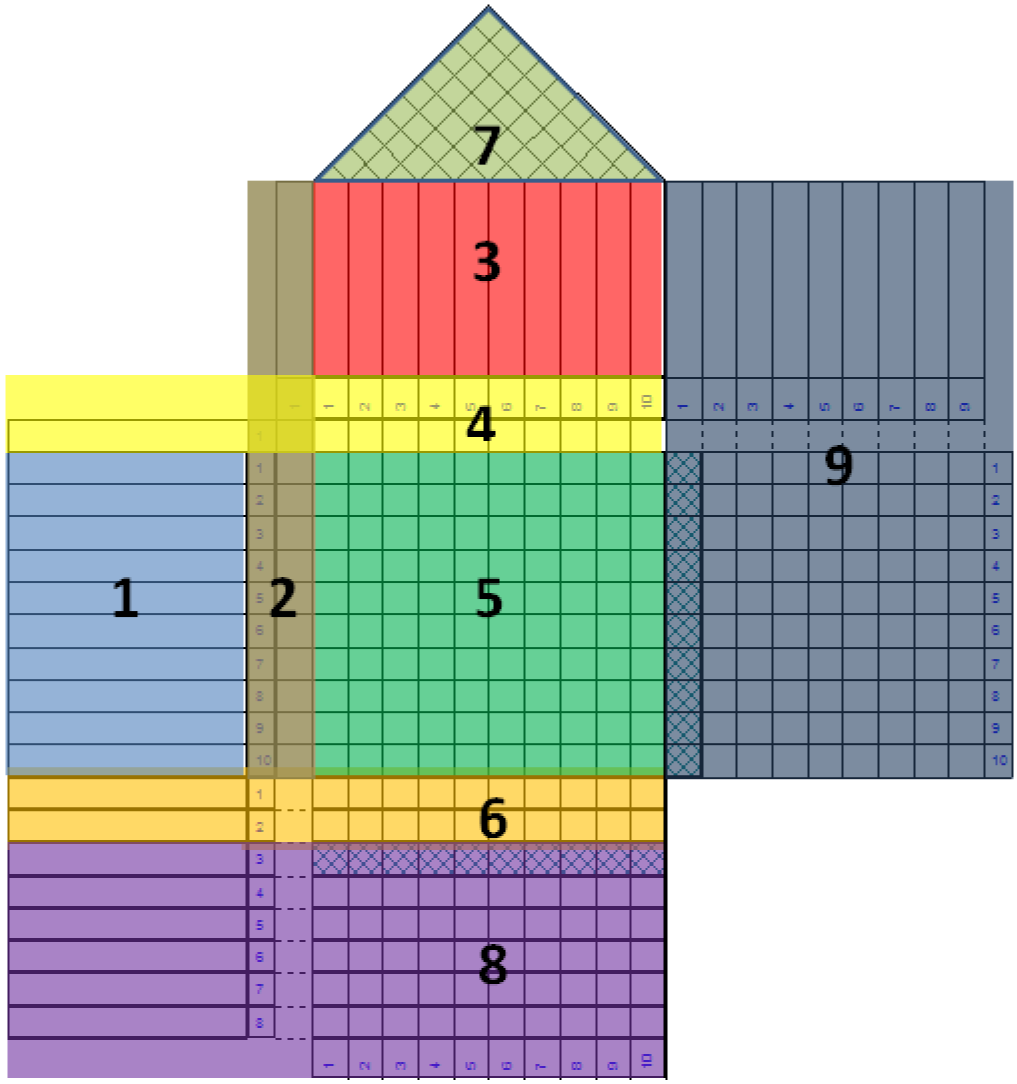

Figure 1.6. Common Contents of a Basic House of Quality

The HOQ is divided into sections with the following information:

1. Rows on the left are attributes that represent customer requirements. These requirements often begin as vague ideas that require analysis to achieve further definition.

2. The requirements are accompanied by a rating which quantifies the customer's desirability for each, with customer preference given to higher rankings.
3. The customer desirability Critical-to-Satisfaction requirements (CTSs) are found in the columns toward the top of the matrix. CTSs are engineering specifications that are defined in order to meet the customer requirements. They are traditionally design features within the product development process, but in the biomass supply model they are conditions of the feedstock production process. For each customer requirement, there should be at least one CTS designed to meet that need. Each customer requirement should have at least one corresponding CTS, but it can have multiple CTSs . If the CTS involves increasing or decreasing the value of a parameter, such as moisture content or bale size, an arrow indicating the direction of change can be found in the columns directly above.
4. Because the CTSs are engineering specifications, they must be accompanied by the direction required to satisfy the customer, such as moisture content being reduced or density being increased, for example.
5. With the customer requirements and proposed CTSs in place, the central construction of the HOQ can take place. This happens within the relationship matrix at the center of the HOQ. The relationship matrix determines how strongly each customer requirement is affected by each CTS, if at all. Because solving this complex system can be uniquely complicated, it is important to understand where relationships exist and how strong they are, as one solution may apply to more than one requirement. This quantification typically has four options:

- Strong relationship (value 9)
- Medium relationship (value 3)
- Weak relationship (value 1)
- No relationship (value 0)

6. Below the relationship matrix are importance rankings that quantify the technical importance (usually on a scale of 1-5) of the CTSs. The highest importance rankings may be viewed as the CTSs of most significance.
7. The roof of the HOQ forms the CTS correlation matrix which correlates, positively or negatively, the relation between each proposed CTS. Correlations are typically classified as strong negative, weak negative, none, weak positive, or strong positive. It is important to determine how each CTS can affect another, as CTSs can work together or they can adversely impact one another, in which case a trade-off would have to occur. For instance, a CTS that reduces transportation costs by specifying a moisture content under 25% conflicts with a CTS that increases process efficiency by allowing 30-50% moisture in the biomass. They therefore have a strong negative correlation.
8. Finishing out the bottom of the HOQ are competitive benchmarks, targets and limits, and the technical difficulty rating. Competitive benchmarks show how well the competition has satisfied CTSs to meet customer requirements. A lack of competitor-satisfied CTSs may indicate a niche opportunity. Targets and limits set measurable engineering goals for each CTS and specify within what limits the CTS must stay to still satisfy customer requirements. The Technical Difficulty ratings specify the level of difficulty required to fulfill each CTS. They may be

subjectively determined from the correlations and previous experience and rely on the company's technical abilities.

9. To the right of the relationship matrix, the planning matrix can be used to set a benchmark for product or service development goals and provides additional guidance for moving forward with the proposed CTSs.

Yang outlines several points of analysis to consider once the HOQ has been constructed (2008):

- Blank or weak columns indicate CTSs that do not correlate well to customer requirements and may need to be eliminated from consideration.
- Blank or weak rows show vulnerabilities where a customer requirement is not being satisfied by a strongly correlated CTS.
- Conflicts are technical assessments that work against customer requirements.
- Significant points are CTSs that correspond to multiple customer requirements.
- "Eye Openers" are opportunities where neither the company nor the competition is properly addressing customer requirements.

OBJECTIVES

The primary objective of Part I of this research is to develop Quality Function Deployment as a quality tool for the biomass supply system for cellulosic ethanol production. This will be accomplished through the following sub-objectives:

- Develop a method for gathering and analyzing the Voice of the Customer from biomass conversion experts (the customer).
- Construct a House of Quality that details the qualities desired by those customers and proposes engineering measures for satisfying those requirements.
- Demonstrate that Quality Function Deployment is a quality tool that can be applied towards a supply process within agricultural engineering.

METHODS

In this research, the basic House of Quality is constructed with VOC information gathered from researchers of biomass-based fuel conversion and refining processes. The Voice of the Customer is gathered from survey data using a single-pass Delphi technique, and that information is organized, analyzed, and presented using Quality Function Deployment and its associated techniques.

Finding the Voice of the Customer

Identifying the Customer

Conducting VOC research does not necessarily mean that a large sample size and statistical analyses are required (Roman, 2011). Although customers are not typically subject matter experts, the customers of this study were specifically selected for their expertise. Because VOC techniques for a biomass supply model require understanding of the real-world perceptions and expectations, experts were selected who have experience converting the product into a useable fuel. These individuals should be able to describe the biomass qualities they require.

A network of biomass conversion experts starting within Oklahoma State University and expanded to include individuals from universities and national laboratories throughout the U.S. formed the pool of customers representing biofuel researchers. Experts within OSU as well as collaboration partners and former colleagues of OSU researchers were identified quickly, while an extensive search of published articles, presentations, and national biomass programs revealed additional survey candidates from across the country. As individuals were surveyed, names of other prospective researchers were shared to grow the pool. In addition to scientists and engineers working to improve and economize methods of biofuel conversion, those working within biorefineries are also considered customers of the biomass supplier. To form this group of industry experts, reports, proposals, and government summaries identified entities involved in biomass conversion, specifically in cellulosic conversion of feedstocks to biofuels.

Developing a Customer Survey Instrument

Throughout the process, participation in developing the HOQ was much lower than anticipated. Although the Delphi method was the intended instrument for the QFD process, the final method that was developed for this research was a single-pass form survey. The survey included a cover letter that explains the purpose and importance of the survey results to respondents. The letter stressed that responses would be held confidential and not shared outside the QFD team. This means that no responses were shared with other participants (respondents) in the study and no identifying information (such as name, institution, etc.) was requested. Each participant's state of operation was asked only to develop an idea of the distribution of respondents throughout the country. It was also explained that information resulting from this study would come only from aggregating the responses in an attempt to form consensus.

For the case of the biorefinery input supply study, specific, closed questions were asked of researchers and refiners aimed at specific suggested biomass qualities. Open-ended questions were limited in number but allowed the customers to provide additional information that was not specifically requested.

Building the House of Quality

Analyzing the Voice of the Customer

An affinity diagram was used to organize information from all respondents into categories of similar discussions so that customer requirements were not repeated and that the ideas were organized for further discussion. The responses were listed in tables according to the conversion method the customer was using. The customer requirements were also collected into a pairwise comparison matrix to determine the importance rating of each of the main customer concerns. The requirements and their resulting importance ratings filled the first section of the House of Quality matrix.

Populating the House of Quality

The House of Quality was populated according the definitions of each section as previously specified.

1. The VOC statements were transferred from the affinity diagram as customer requirements.
2. Depending on the responses from the survey, the customer desirability was determined directly from customer rankings or indirectly by the number of requests for that requirement.
3. Because the customer is also a subject matter expert in this case, the CTSs were often defined by the Voice of the Customer.
4. The direction of improvement was interpreted directly from the VOC. If the customer wanted the “material not to be very wet”, and the CTS was defined as “reduce moisture content”, the direction of improvement was an “increase” in the reduction of moisture.
5. The CTSs were than analyzed subjectively by the QFD team to determine the relationship each CTS had to each customer requirement, and the values were entered accordingly: strong (9), moderate (3), weak (1), and none (0).
6. An importance score for each CTS was calculated by summing up the multiplications of (customer desirability rating) x (relationship value).
7. The CTSs were analyzed by comparing the engineering objectives and their associated directions of improvement to determine if the CTSs worked toward the same goal (positive correlation), if their objectives conflicted (negative correlation), or if they had no impact on each other (no correlation).
8. Since this specific QFD method was being developed and had no current testing or validation, no competing research institutions were benchmarked to evaluate how they satisfy the CTSs, if at all.

Because the customer is also a subject matter expert in this case, the survey asked for desired parameter values if the customer could provide them. These became the targets and limits.

The technical difficulty was determined by discussing the technical capabilities of OSU's Biosystems and Agricultural Engineering Department along with the perceived capability of other departments and evaluating OSU's ability to meet those targets and stay within the specified limits.

9. Once again, because this specific QFD method was in development, no competing research institutions were benchmarked to evaluate how they satisfy the customer requirements, and no plans were laid out for how OSU could meet those requirements. However, if the QFD tool is proven to provide utility for determining the required qualities of biomass as a biorefinery input, the planning matrix should be completed as a guide to future proposal creation.

Pilot Study

Quality Function Deployment was applied to the biorefinery supply case in a pilot study seeking the input of bioconversion researchers and refinery experts from around the country. Using the Delphi Technique, surveys were sent out to the customers and those that were returned were analyzed. The methods used were evaluated to determine if they could be successfully deployed in the industry.

The pilot study was evaluated to determine what improvements could be made before the QFD was deployed as a more-refined tool within the agricultural research community.

Specifically, the pilot study was evaluated for improvements by asking the following questions:

Identifying the customer:

- Do the selected individuals represent the actual customer base?
- Were there multiple respondents for each of the three primary conversion methods (hydrolysis, pyrolysis, and gasification)?

Developing concise, meaningful questions:

- Were there any questions that the respondents answered with different definitions?
- Did the respondents answer each question?
- Did the respondents provide more than one value when asked quantitatively?

Analyzing the Voice of the Customer:

- Did the respondents arrive at a consensus for most or all of the questions?
- Did different respondents provide conflicting information?
- Were any of the provided answers merely “guesses”?

Analyzing the House of Quality:

- Do any CTSs fail to correlate well to customer requirements?
- Are any customer requirements left unsatisfied?
- Do negative correlations exist between CTSs?
- Do any CTSs address multiple customer requirements?

Deployment

The actual methods used in the deployment of the quality tool depended on the analysis of the pilot study and its procedures. If the customer pool needs to be refined, it could be expanded to researchers in more universities and state and national laboratories throughout the country, as well as to non-technical staff and managers at cellulosic ethanol refineries who may have a database of knowledge without the hands-on research experience. If the customer pool is too large, it could be contracted to include only those individuals currently receiving biomass material and not those who plan to.

If multiple parameters for a single quality are defined, if the conglomerate of results contains conflicting information, or if respondents are involved with more than one conversion technique, it may be important to evaluate the responses according to the conversion method used. This may require restructuring the survey to allow for better analysis. If the customers fail to reach a consensus, if CTSs fail to correlate well with customer requirements, or if any of the customer requirements are left unmet, the responses may need to be evaluated by the customer type, researcher or refiner.

If the customers fail to answer all the questions or provide vague responses to open-ended questions, then the VOC research method may need to be modified. Customers may need to be gathered into the same room and led in a round-robin discussion to extract ideas from the entire group. Responses from one individual may stimulate addition conclusions that other individuals might not arrive at on their own. If the round-robin does not have a good leader, however, it could lead to one large argument where nothing conclusive is ever decided. In that case, a face-to-face meeting with the customer pool broken into smaller groups may be necessary to provide a large enough group to get information flowing without providing too large of a group to arrive at a consensus about a quality topic. If the face-to-face meetings are not possible, then the survey will need to be revamped to elicit in-depth responses from the customers.

Validation

The introduction, the procedures, and the blank House of Quality provided in Appendix A were sent to biomass production experts at a national laboratory. A web conference was then held to introduce how the QFD tool was developed for the biomass supply system, how it was applied in this study, and what the outcomes were. Those experts were asked to give their feedback on the potential utility of the tool and whether they would be supportive of continued, expanded QFD research for biomass supply systems..

RESULTS AND DISCUSSION

Results

Pilot Study

The researcher customer pool was comprised of engineering faculty and staff from universities and national laboratories around the U.S. The biorefinery customer pool was comprised of lead engineers from ethanol refinery plants with cellulosic conversion facilities currently planned for construction.

The cover letter that was developed with the initial survey is shown in its entirety in Appendix B.1.

For the case of the biorefinery input supply study, specific, closed questions were asked of researchers and refiners that sought the type of material utilized, conversion method used, preferred moisture content, packaging type, and contaminants. Open-ended questions were limited in number but focused on information that could not be packaged into multiple choices, such as describing the biomass supply process, frustrations or complications with the current supply method, and additional qualities of biomass that may be desired.

To eliminate irrelevant information from each group, similar but distinct surveys were created for the researcher group and the refinery group and are provided in Appendices B.2 and B.3, respectively. The categories of qualities sought are shown in Table 1.1.

Table 1.1. Suggested Quality Categories for the VOC Survey

State of Operation	**Current Supply Method**	**Complications with Method**
Biomass Materials Utilized	**Time for Biomass to Sit**	**Preferences or Dislikes**
Switchgrass	0-3 months	Size
Forage Sorghum	3-6 months	Density
Prairie Grasses	6-12 months	Conditioning
Corn Stover	>12 months	Additives
Other		Other
Preferred Packaging Method	**Contaminants**	**Preferred Moisture Content**
Small Square Bale	Twine	Less than 10%
Large Square Bale	Plastic	10-25%
Large Round Bale	Wire	25-50%
Loose Material	Soil	Greater than 50%
Other	Wild Animal Carcass	Reasoning
Reasoning	Other	
Primary Conversion Method	**Preferred Pretreatment Method**	**Anticipated Throughput**
Pyrolysis	Reasoning	
Hydrolysis	**Minimum Preferred Energy Density**	**On-Site Storage Capacity**
Gasification	Reasoning	
Other	**Premium Qualities**	**Dockage Qualities**

The Voice of the Customer was collected and summarized in Tables 1.2-1.4 to show the various responses in relation to the conversion process (Tables 1.2-1.3) or the type of biomass (Table 1.4).

Table 1.2. Survey Responses – State of Operation

	Pyrolysis	Hydrolysis	Gasification	Total
Oklahoma	0	1	2	3
Utah	0	0	1	1
Iowa	1	0	1	2
Mississippi	1	0	1	2
Colorado	0	1	1	2
Total	2	2	6	

Table 1.3. Survey Responses – Qualities Grouped by Conversion Method

	Pyrolysis	Hydrolysis	Gasification	Total
Biomass Material				
Switchgrass	2	2	6	10
Forage Sorghum	0	1	2	3
Prairie Grasses	0	1	0	1
Corn Stover	0	1	2	3
Wood Chips	1	2	3	6
Other Lignocellulosic Material	0	2	2	4
Moisture Content				
<10%	2	2	5	9
10-25%	0	1	2	3
25-50%	0	0	0	0
>50%	0	0	0	0
Packaging Method				
Small square bale	0	0	0	0
Large square bale	1	1	3	5
Large round bale	0	1	0	1
Loose material	0	1	1	2
Preprocessing/Pretreatment				
Grinding	1	0	5	6
Drying	1	0	3	4
Hydrothermalysis	0	1	0	1
Steam Explosion	0	1	0	1
Dilute Sulfuric Acid	0	1	0	1
None	1	0	1	2
Contaminants				
Soil	2	2	4	8
Wire	2	3	2	7
Plastic	0	1	1	2
Wild animal carcass	1	0	2	3
Twine	0	0	1	1

Table 1.4. Anticipated On-Site Storage Time (months)

	0-3	3-6	6-12	>12
Switchgrass	2	5	2	0
Forage Sorghum	1	3	0	0
Prairie Grasses	0	1	0	0
Corn Stover	0	2	1	0
Wood Chips	1	3	2	0
Other Lignocellulosic Material	1	2	1	0
Total	5	16	6	0

Each respondent indicated that they currently process biomass using one or more conversion techniques: gasification, pyrolysis, and hydrolysis, with gasification being the most common method. Gasification may be most-used because it is the oldest and most developed conversion alternative (BRDB, 2011a). Instead of completely combusting the biomass, gasification partially burns the carbon-based materials at temperatures of 600-900°C using controlled amounts of oxygen to produce syngas which can then be fermented into ethanol or other alcohols. Pyrolysis produces intermediate bio-oils through slow heating for longer contact times or through rapid heating for shorter contact times at heating rates of 450-500°C. The high-density bio-oils can be further processed into diesel- or gasoline-based fuels. Hydrolysis, which normally requires pretreatment, typically uses enzymes to break down cellulose and hemicellulose into simple sugars which are then processed by microbes into fuels.

Not all questions received responses from every participant, but, as shown in Figure 1.7 some areas received a lot of attention. The key issues identified were shown in Figure 1.8 to be moisture content, preprocessing, packaging, and contaminants. Low moisture content was always preferred (at least less than 25%) but for multiple reasons:

- Reduced chance for biological degradation
- Easier for handling systems
- Reduced steam heating demands (for hydrolysis)
- Less water for gasifier to vaporize

One researcher indicated that the biomass did not necessarily need to be bone-dry, and that in fact some moisture may help efficiency as less water would need to be added later in the process.

Very few chemical or thermal pretreatment methods were given with preference for no treatments receiving multiple recognitions; however, grinding and drying were commonly stated as being preferred for preprocessing. Large bale form was the preferred packaging method for ease of handling, although most respondents indicated the material would have to be ground before it could be processed. Contaminants were commonly identified as being undesirable. While soil and wire were agreed upon as being harmful to the process, plastic, twine, and wild animal carcasses were not common throughout the responses. In fact, one response explained that "because it is biological material", animal carcass could have a "neutral or slightly positive affect" depending on the process.

No preferred energy density was identified; general comments simply indicated that higher was better. Respondents agreed that biomass should be ground before conversion begins, but none were able to identify or agree on a size. Responses ranged from 1-15mm to Wiley mill preferred, with Hammer mill or tub grinder possible to provide increased overall efficiency. When asked for the anticipated biomass throughput for commercial production plants, most respondents did not provide an estimate, but the responses that were received included:

- 25-200 tons/day for a smaller plant and 2,500-15,000 tons/day for a large industrial gasification plant (with no indication as to run time per day),
- 1 kg of biomass per kW output, and
- up to 25 kg/hour.

The responses were grouped into similar categories using the affinity diagram shown in Figure 1.7.

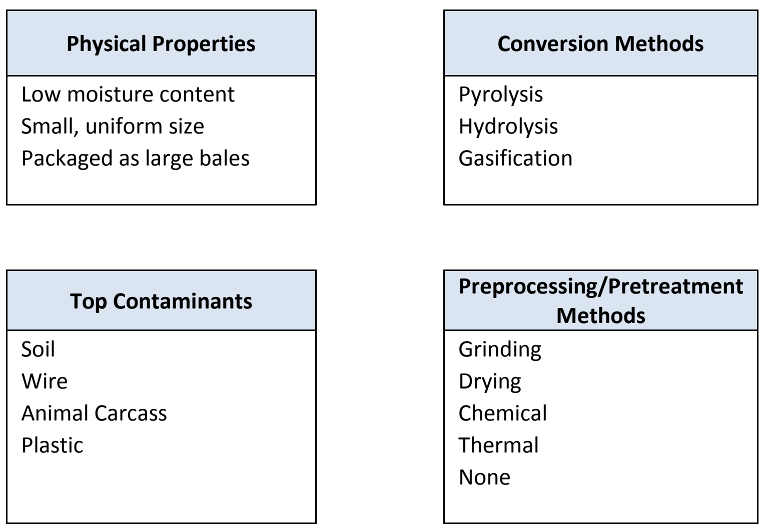

Figure 1.7. Affinity Diagram of Customer Responses

The pairwise comparison matrix in Figure 1.8 was constructed using the number of responses in each category to determine the dominating quality out of the pair. Starting on the top left stair step working down, *Low Moisture Content (A)* was considered more important than *Large Packaging Method (B)*. *Small Size (C)* was considered more important than *Low Moisture Content (A)*. *Lack of Contaminants (D)* was considered more important than *Low Moisture Content (A)*. Moving to the middle section, *Small Size (C)* was considered more important than *Large Packaging Method (B)*. *Lack of Contaminants (D)* was considered more important than *Large Packaging Method (B)*. And at the bottom step, *Lack of Contaminants (D)* was considered more important than *Small Size (C)*. The VOC with the pairwise comparison matrix was then assigned importance ratings based on the outcomes of the pairwise comparisons, with five being the highest rank.

Pairwise Comparison Matrix

		A Low Moisture Content	B Large Packaging Method	C Small Size	D Lacks Contaminants	Total
A	Low Moisture Content					1
B	Large Packaging Method	**A**				0
C	Small Size	**C**	**C**			2
D	Lacks Contaminants	**D**	**D**	**D**		3
	Total	1	0	2	3	
	Customer Desirability	**2**	**1**	**4**	**5**	

Figure 1.8. Pairwise Comparison of the Top Customer Focus Areas

With the VOC analyzed, each section of the HOQ was constructed as illustrated by Figure 1.6.

- Sections 1 and 2: The customer requirements and the determined customer desirability were transferred to Figure 1.9.

- Sections 3 and 4: Engineering objectives were defined in Figure 1.10 to satisfy customer requirements. The directions of improvement were added as: *increase* drying time in the field; *decrease* material size; and *increase* processing of material to remove contaminants.
- Sections 5 and 6: CTS evaluations created relationship values between the CTSs and the customer requirements as seen in Figure 1.11. The calculations of *customer desirability rating* times *relationship value* yielded importance scores, from which importance percentages were calculated as the *current importance score* divided by the *sum of all importance scores*.
- Section 7: The roof of the House of Quality in Figure 1.12 shows a positive relationship between *Use current large round or square balers* and *Grind bales to reduce size* because the tub grinding, a method of common response, it designed to be fed with large bales. The roof shows a negative correlation between *Use current large round or square balers* and *Further process material to remove contaminants* because the current balers are unable to further process material.
- Section 8: Targets were set in Figure 1.13 along with the assessed difficulty of implementing each CTS.
- Section 9: As previously stated, the planning matrix was not used.

Low Moisture Content	1	2.0
Large Packaging Method	2	1.0
Small size	3	4.0
Lacks Contaminants	4	5.0
	5	
	6	
	7	
	8	
	9	
	10	

Figure 1.9. HOQ with Customer Requirements and Desirability

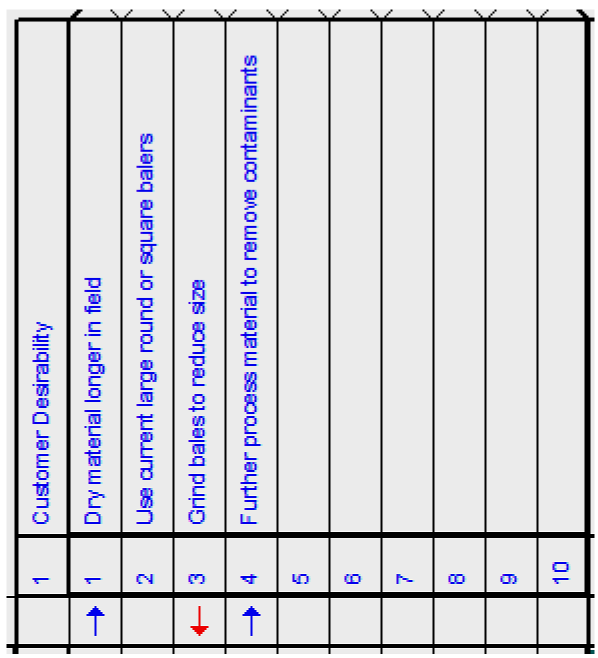

Figure 1.10. HOQ with Critical-to-Satisfaction Requirements and Directions of Improvement

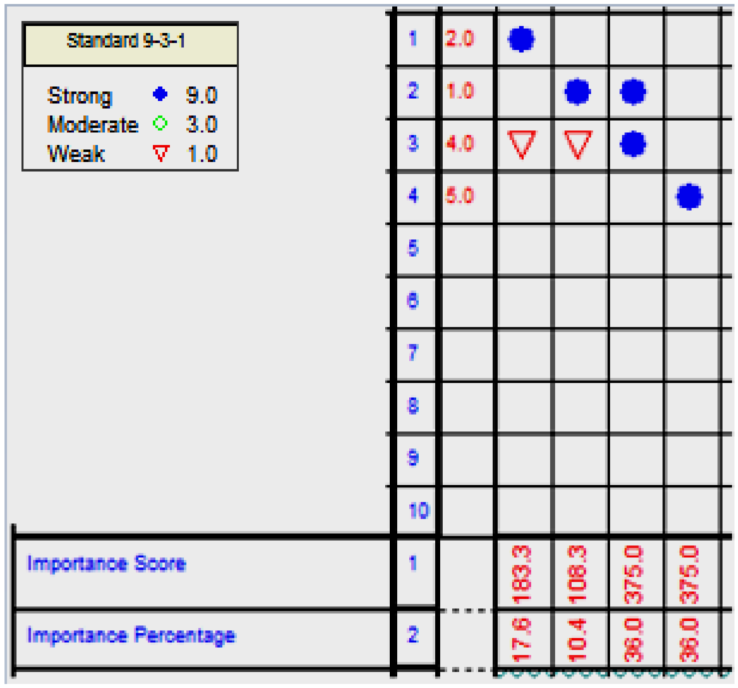

Figure 1.11. HOQ with CTS Relationships and their Importance Scores

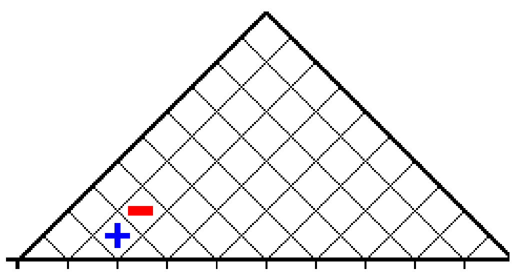
Figure 1.12. Roof of the HOQ with Correlations

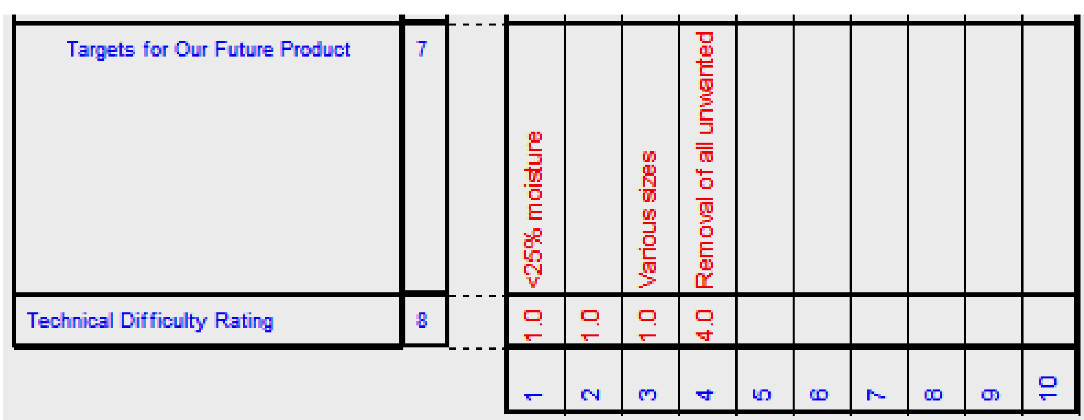

Figure 1.13. HOQ with Targets and Technical Difficulty Rating

With the individual sections of the matrix completed, the entire House of Quality is shown in Figure 1.14. Although the CTS *Dry material longer in the* field has a technical difficulty of one, the implications of leaving material on the ground exposed for a longer time create logistical difficulties of ensuring weather does not negatively affect the material. The House of Quality shows that the most commonly addressed issues with biomass supply are, with Importance Ratings (high number is more important)

- Lacks contaminants (5),
- Small size (4),
- Low moisture content (2), and
- Large packaging method (1).

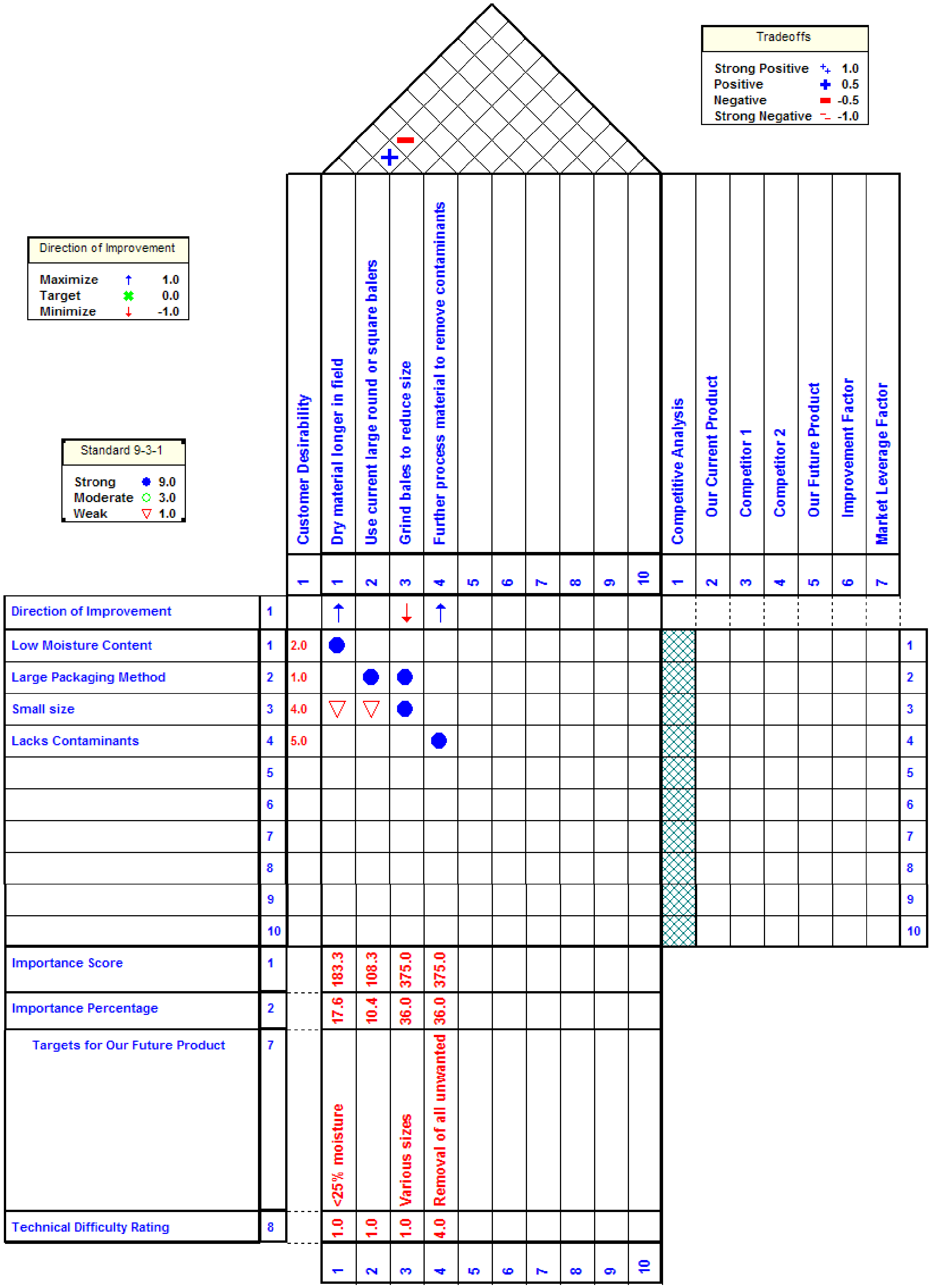

Figure 1.14. Completed HOQ showing Analysis Scores

A summary of customer responses is provided in Table 1.5 to show the complications that arise in conducting surveys. In general, responses to written surveys may only occur at 20-30% (Yang, 2008). For this study, Yang's response rate proved to be accurate. Survey respondents may indicate that they do not have the required expertise to accurately provide information requested. Or, those surveyed may work in an environment or for a specific company where the information is deemed confidential. In that case, the information may only be available if it is ever published, which could be far enough into the future to significantly decrease its value.

Table 1.5. Survey Respondent Statistics

	Surveys Sent	**No Response**	**Surveys Declined**	**Surveys Returned**	**Percentage Returned**
Researchers	19	7	4	8	**42.1%**
Biorefineries	8	5	3	0	**0.0%**
Total	**26**	**13**	**5**	**8**	**29.6%**

Analysis of the pilot study methods revealed several areas of attention:

- Until cellulosic biomass conversion methods have developed far enough that refineries are willing to share their biomass requirements and cellulosic ethanol production facilities are on-line at commercial-scale capacity, the actual customer or end user of the biomass will be the conversion researchers trying to further development of the processes.
- Customers who utilized different materials or different conversion methods did not specify which material or conversion method each answer applied to, or if it

applied to all. The customers were not clearly led through the process of doing so.

- Too many open-ended questions were asked, and not enough concise definitions of biomass quality were sought. Additionally, there were only 15-16 questions, yet the format of the survey took up the entire space on two pages.
- Response time varied and many customers did not respond to the survey.

Additionally, most of the ethanol production personnel did not even acknowledge that they had read the letter and survey. The refiners that sent any type of response indicated that they could not share the requested information as it was regarded as confidential given the impact it had on their processes, some of which were hinted to as proprietary. Responses from researchers showed that working in conjunction with biorefineries often restricts what knowledge the researcher is allowed to publicly divulge, as proprietary processes and confidentiality agreements both arose during discussions with researchers. Other responses indicated that the answers provided were potential ideas rather than what was actually sought after in conversion research.

Deployment

The results of the pilot study were evaluated to determine if adjustments to the survey instrument or procedures needed to be made. Analysis of the pilot study revealed several changes that needed to be made before the QFD technique was further deployed.

- Since there are currently no cellulosic ethanol refineries in operation, and because of the protections biorefineries have for these developing conversion processes, the production facilities cannot be considered the customer at this time. They will of course be the primary customers once the industry has taken off. Until then, researchers will be the customers of biomass suppliers and were therefore the only customers considered for deployment of the QFD tool.

- Although a round-robin was discussed at length, it was determined that this type of VOC collection tool could not be implemented in the study's timeframe and that the Delphi method would again implemented.
- The survey was greatly redefined to suggest more possible biomass quality characteristics. The survey was broken down into categories and restructured into a table format. This allowed for more questions while taking up no addition pages. The format also provided an easier, guided flow for filling out the survey.
- The survey was distributed to researchers at a bioenergy conference held at Oklahoma State University is Stillwater, Oklahoma. The purpose of the study and guidelines were explained at the conference.
- Researchers were asked about specific biomass feedstocks. They were also directed to fill out a unique survey for each conversion method they utilized. Since the survey was included with each conference attendee's registration package, designation was also required to distinguish between faculty/post-doctoral researchers and graduate students. Because information from graduate students likely reflects their faculty's thoughts, these surveys were not included in the deployment analysis.

The deployment survey is shown in Table 1.6. A new survey introduction letter and the survey itself are provided in Appendices C.1 and C.2, respectively. The survey was given to approximately 30 conference registrants with only five returned; a 16.7%

response rate. The responses from the deployment survey were grouped into the affinity diagram in Figure 1.15. These responses, along with any desired parameters, were developed into the House of Quality in Figure 1.16. The deployment House of Quality defines with more clarity the Voice of the Customer and the CTSs required to satisfy customer desires. Analysis of the HOQ shows similar importance for all CTSs, with "large bales" being most important and "covered storage" being least important. Therefore, the highest priorities from this HOQ should be to:

- Use a large baler for high package density and large size.
- Find the best balance for achieving optimum moisture content.
- Develop ways to remove contaminants from the biomass before processing.

Package Properties
Large package size
High package density
Not too wet or dry
Protected from rain

Material Properties
Uniform material size and shape
Small material size
Not too wet or dry

Top Contaminants	
Metals	Soil
Mold	Twine
Nitrates	Plastic
Lignin	Animals
Soil	Weeds

Physiochemical Properties
Low ash content
High energy content

Figure 1.15. Affinity Diagram of Deployment Responses

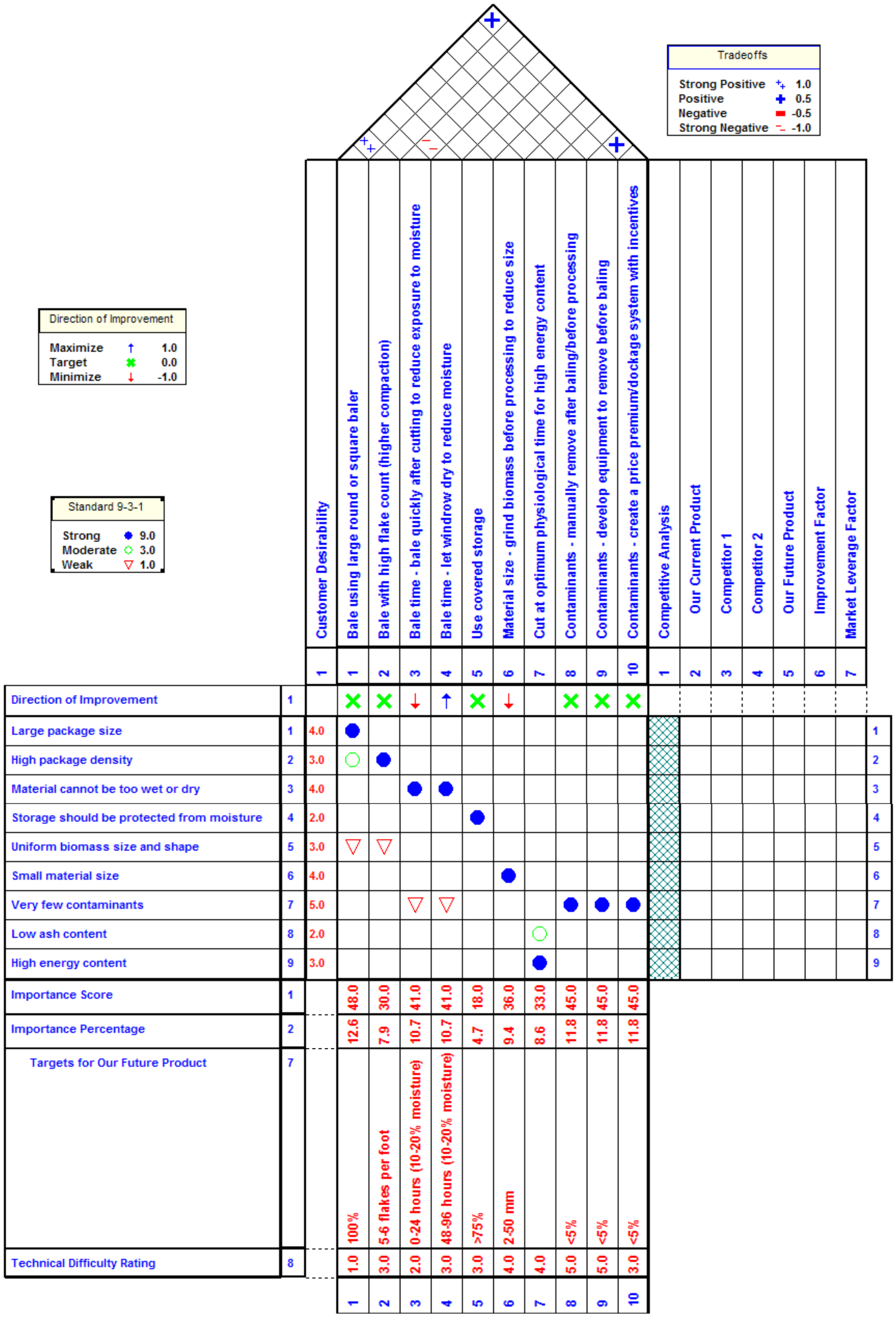

Figure 1.16. Completed HOQ for the QFD Deployment

Validation

Experts at Idaho National Laboratory (INL) were identified to give their evaluation of the QFD process for the biomass supply system based on their work in several areas of biomass production and conversion. At the conclusion of the web conference, questions were asked by both sides to determine the potential utility of the tool developed through this research. The team of experts at INL responded that this study was a good start in the right direction, that it shows promise, and, because of the utility they saw in this method, that it has potential for a widespread impact. They were interested in becoming involved to help develop the tool even more, as they thought that correct implementation could lead to developed standards for the industry and allow the industry to better define its quality requirements. The biggest suggestion moving forward was to develop a better customer survey instrument, and INL believes they have the people and the tools to provide a significant contribution.

CONCLUSIONS

This study shows how Quality Function Deployment and the House of Quality matrix can be used to evaluate quality parameters of biomass for the conversion process and to support a plan for providing those qualities. However, researches are for the most not yet confident of the biomass qualities needed for biofuels conversion processes. This notion is supported by feedback indicating that some of the answers were potential ideas rather than practices. Yang argues that engineers, scientists, and technicians are constantly creating documents, calculating statistics, compiling reports, and building tools (2008).

Effectively, they are generating enough useful information so that the next step of the process may commence or continue. That holds true for the current biomass supply case. As cellulosic conversion techniques mature, researchers should develop a stronger consensus of what biomass qualities are needed. Also, bringing cellulosic conversion plants online should also allow producers to contribute their voices. In time, QFD should be revisited for the biomass supply scenario.

In the meantime, the Biomass Research and Development Board and the USDA-ARS have identified challenges currently facing the biomass conversion industry. Although the sources that provided these challenges were not obtainable, they are attributed to DOE and USDA experts as well as specialists from national laboratories (BRDB, 2011b and Fales et al, 2007). These challenges are summarized in Table 1.6.

Table 1.6. Biomass Processing and Development Challenges
(developed from BRDB, 2011b and Fales et al, 2007).

Biomass Production	Develop sustainable BMP's for biomass feedstock production Develop low-cost production systems Integrate new energy crops and management strategies into current systems Improve cellulose yield of energy crops Develop cropping systems to improve production efficiency Produce energy crops with low ash composition
Harvest and Collection	Increase equipment capacity Develop equipment that reduces pretreatment requirements Develop equipment and management practices that reduce environmental impacts Develop or modify equipment to increase feedstock drying efficiency
Storage	Reduce dry matter losses Increase storage capacity Reduce compositional breakdown Reduce requirements for additional pretreatments Prevent compositional change of cellulosic material
Preprocessing	Increase equipment capacity Increase equipment efficiency Increase handling efficiencies Maximize material bulk density Increase drying and grinding efficiencies Reduce impacts of preprocessing on material composition and pretreatment
Transportation and Logistics	Increase transport capacity Maximize material bulk density Increase handling efficiencies Minimize social impacts Develop advanced efficient engineered supply system Reduce supply logistics to less than 25% of total ethanol production costs Develop a common-commodity feedstock supply system

INDUSTRY IMPACT STATEMENT

When producers know what qualities of biomass are desired for ethanol, they can develop the technologies that specifically target production of those biomass qualities. The use of QFD techniques will play an important role in making qualitative and quantitative determinations that lead to reduced costs of high-quality biofuels.

CHAPTER II

ASSESSMENT OF CURRENT BIOMASS RESEARCH PROGRAMS AND THEIR ABILITY TO SATISFY THE CUSTOMER REQUIREMENT MATRIX

INTRODUCTION

World energy consumption is predicted to grow 44% between 2009 and 2030 (RFA, 2009). As energy demand increases, researchers work to find technically feasible and economically viable methods of producing renewable fuels as alternatives to traditional petroleum-based transportation fuels. In the U.S., government support of these programs comes with cooperation from the U.S. Department of Agriculture (USDA) and the Department of Energy (DOE). Some programs within these agencies include the Biomass Program as a part of Energy Efficiency & Renewable Energy (EERE) within the DOE, the Agriculture and Food Research Initiative (AFRI) under the USDA, and the Biomass Research and Development Initiative (BRDI) as a joint venture of the USDA and DOE.

According to the Renewable Fuels Association, American ethanol production reached 13.5 billion gallons in 2010, or about ten percent of U.S. gasoline demand, enough to replace 445 million barrels of oil (RFA, 2011). Iowa leads the nation in ethanol production with nearly 3.6 billion gallons. Ethanol refineries operate in 29 states with 560 facilities under construction or expansion. Over the past 11 years, the number of ethanol biorefineries has increased by 150 to 204 in January 2011, while production capacity has grown by nearly 11.75 million gallons.

Although the operational capacity of corn-based ethanol plants in the U.S. was approximately 10.5 billion gallons and growing in 2009, it was projected that this number could only grow to about 15 billion gallons in 2014 without adversely affecting natural resources (Sanderson, 2007). As of January 2011, more than 20 demonstration- and pilot-scale plants currently operating in 17 states utilize advanced biomasses such as algae, corn stover, grasses, and woody biomass. However, many companies lack the capital to construct commercial-scale biorefineries (RFA, 2011). With a government mandate of 16 billion gallons of cellulose-based ethanol to be produced by 2022, cellulosic ethanol refineries are being developed all across the United States (Sissine, 2007). Table 2.1 lists those cellulose-based refining plants known to be under development as of May 2009. The given capacity of each refinery is projected, as these plants are not currently online (Khanal and Lamsal, 2010).

Table 2.1. Cellulosic Ethanol Plants Under Development in the U.S. as of May 2009 (developed from Khanal and Lamsal, 2010)

Company	**Location(s)**	**Ethanol Capacity (million gallons per year)**
Abengoa Bioenergy	Kansas(2), Nebraska	34.56
AE Biofuels	Montana	Small-scale
Bluefire Ethanol	California	21.1
California Ethanol and Power	California	55
Coskata	Pennsylvania	0.04
DuPont Danisco Cellulosic Ethanol	Tennessee	0.25
Ecogin	Kentucky	1.3
ICM	Missouri, Idaho	19.51
Iogen Biorefinery Partners	Idaho	18.49
Lignol Innovations	Colorado	2.5
Mascoma	Tennessee	2.01
Mascoma/New York State	New York	5
Mascoma/Michigan State	Michigan	40
Pacific Ethanol	Oregon	2.7
POET	South Dakota, Iowa	31.27
Range Fuels	Georgia	20
RSE Pulp	Maine	2.19
Verenium	Louisiana, Florida	37.4
		293.32 total

These cellulosic ethanol plants are distributed across the country throughout 19 states. This geographic distribution can promote regional economic development and allow the plants to optimize conversion technologies for the biomass feedstocks grown in each region. The total ethanol capacity for all these plants is less than 300 million gallons which equates to less than two percent of the 2022 RFA requirement. Of the top 50 bioenergy companies as identified by Biofuels Digest, 20 operate on a commercial scale, nine are demonstration scale, and the remaining 21 are only laboratory scale (Khanal and Lamsal, 2010). These numbers include some bioenergy companies that may not focus on cellulosic ethanol production, which only reinforces the need for biofuel refineries to mature into commercial operations over the next ten years to meet the government mandate.

The lack of sufficient commercial-scale production creates barriers to meeting the 2022 RFS. The most likely hindrance to development of commercial-scale facilities is the financial risk associated with maturing new technologies. Several issues can be identified as still in a state of infancy (Khanal and Lamsal, 2010):

- The feedstock production and handling logistics have not been developed to find the best solution for transporting and storing large amounts of biomass.
- The costs of pretreatment and enzymatic catalysts are currently high.
- Fermentation of cellulosic materials is not commercially efficient.
- The use and value of coproducts that may result from all stages of production have not been realized.
- Long-term support of biofuels can waiver when oil prices fall.

The lack of mature technologies for cellulosic ethanol production means that no production strategy has prevailed as dominant. Therefore, current production costs can vary greatly from $2.27 to $4.92 per gallon. The International Energy Agency predicts that costs may be reduced to as little as $0.95 - $1.32 per gallon with research to develop production processes further (2008).

BACKGROUND

In order to meet these challenges and spur industry growth, the USDA and DOE provide financial support for the research and development of alternative fuels production including cellulosic ethanol. This funding could be used to ensure that biomass quality requirements are being met.

Biomass Research Funding

Biomass Program

The mission of the DOE's Biomass Program is to "develop and transform our renewable and abundant, non-food biomass resources into sustainable, cost-competitive, high-performance biofuels, bioproducts and biopower" (DOE EERE, 2010a). This falls in line with the government's mandate to limit corn-based ethanol production and support development of advanced biofuels such as those produced from cellulosic feedstocks. The program concentrates on two main goals: to meet the 21-billion-gallon goal for advanced (non-corn-based) biofuels in 2022, and to develop mature cellulosic ethanol technologies to reduce costs to $1.76 per gallon by 2017 (DOE EERE, 2010a).

Towards these goals, the Biomass Program has a special focus on integrated biorefineries, that is, refineries that can efficiently convert a wide range of biomass materials into affordable sources of renewable-based biofuels, bioproducts, and biopower while optimizing production economics. Section 9008 of the Food, Conservation, and Energy Act of 2008 (the 2008 Farm Bill), an amendment to the Biomass Research and Development Act of 2000, defines a bio-based product as either “an industrial product (including chemicals, materials, and polymers) produced from biomass” or “a commercial or industrial product (including animal feed and electric power) derived in connection with the conversion of biomass to fuel” (HR 2419, 2008). Figure 2.1 illustrates the distribution of funding within the Biomass Program.

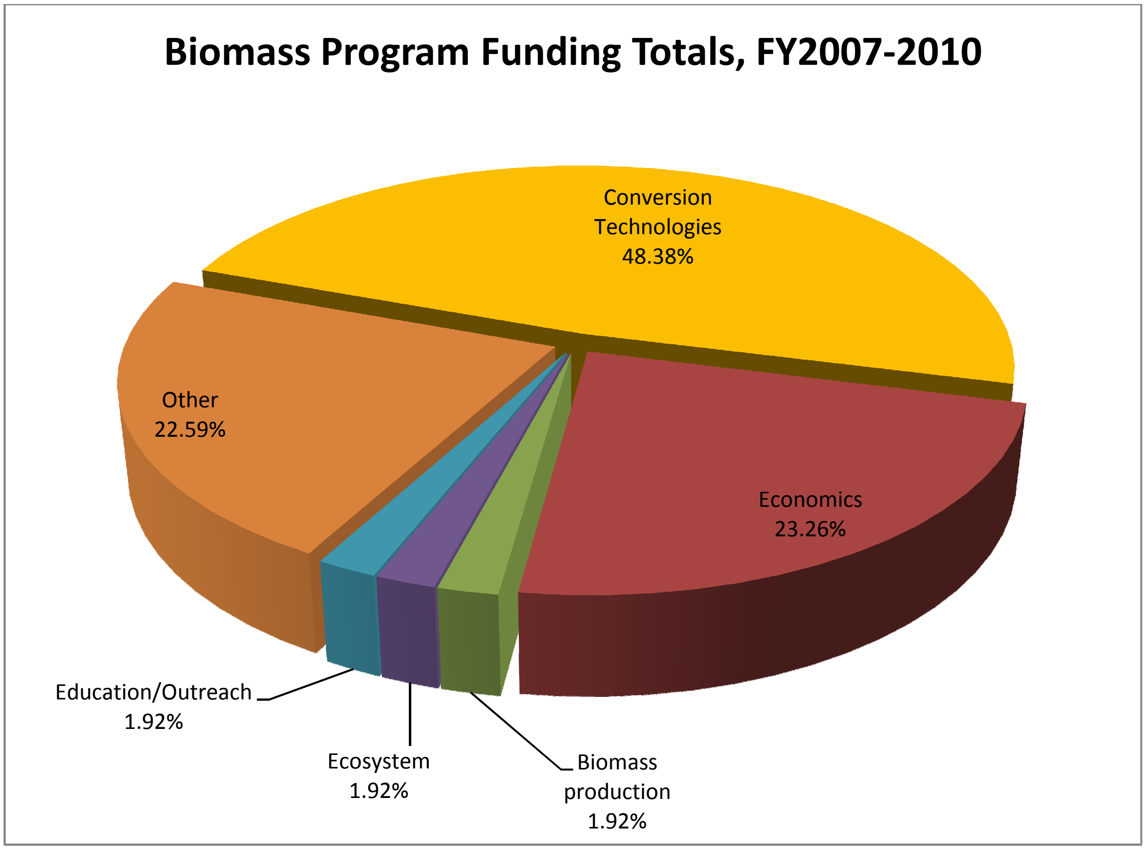

Figure 2.1. Distribution of Biomass Program Funding

The technologies needed to make the biorefining industry competitive with fossil fuel production require intense resources. This requires significant research, development, and deployment investments to help mature the technology quickly (DOE EERE, 2010b). The Biomass Program works to develop the integrated biorefinery industry at pilot, demonstration, and commercial scales, by helping to reduce the risks and financial burdens associated with developing new technologies. The goal is to accelerate deployment of biomass refineries by helping industry partners overcome the challenges associated with financing new technologies, attaining economic viability, utilizing diverse feedstocks across differing geographies and climates, obtaining environmental permits, reaching economic, environmental, and social sustainability, and maintaining consistent research and development (R&D) investments (DOE EERE, 2010b).

In order to understand the processes associated with integrated biorefineries, the National Renewable Energy Laboratory (NREL) in Golden, Colorado is constructing an Integrated Biorefinery Research Facility (IBRF) to provide the cellulosic refining industry with a research facility and an expanded pilot plant (NREL, 2010). The facility will include a 27,000 square-foot high bay and 3,800 square feet of lab space that collaborators without proper facilities or resources can use to achieve their research goals. With a targeted completion date in the fourth quarter of 2011, the IBRF will be available to industry partners collaborating with NREL to ensure that cellulosic ethanol can be produced in an economically feasible and environmentally sustainable way.

Although there are currently no commercial-scale cellulosic ethanol facilities in operation, the Department of Energy has made another significant contribution towards that end. On July 7, 2011, U.S. Energy Secretary Steven Chu announced that the DOE had committed to a $105 million conditional loan guarantee to support POET, LLC in its development of Project LIBERTY in Emmetsburg, Iowa, the nation's first commercial-scale cellulosic ethanol production plant (DOE, 2011). The plant is projected to produce up to 25 million gallons annually by converting primarily corncobs, leaves, and husks to ethanol through enzymatic hydrolysis. POET plans to use this process at 27 of its other ethanol production facilities to eventually produce as much as one billion gallons of cellulosic ethanol per year.

Agriculture and Food Research Initiative

With the 2008 Farm Bill (specifically, Section 7406 of the Food, Conservation, and Energy Act of 2008), the AFRI continues the work of its predecessor, the National Research Initiative (NRI) and is the core competitive grants program of the USDA through FY2012. The purpose of the AFRI is to address problems in farm and ranch efficiency, renewable energy, forestry, aquaculture, food safety, biotechnologies, and rural development (USDA, 2009).

AFRI program awards can fund educational, extension, or research projects, as well as integrated projects incorporating two or more projects in education, extension, research, and conferences. The awards of interest stemmed from the last three program areas listed above and involved research or integrated projects. Figure 2.2 illustrates the distribution of funds awarded to biomass- and biofuels-related research from the AFRI.

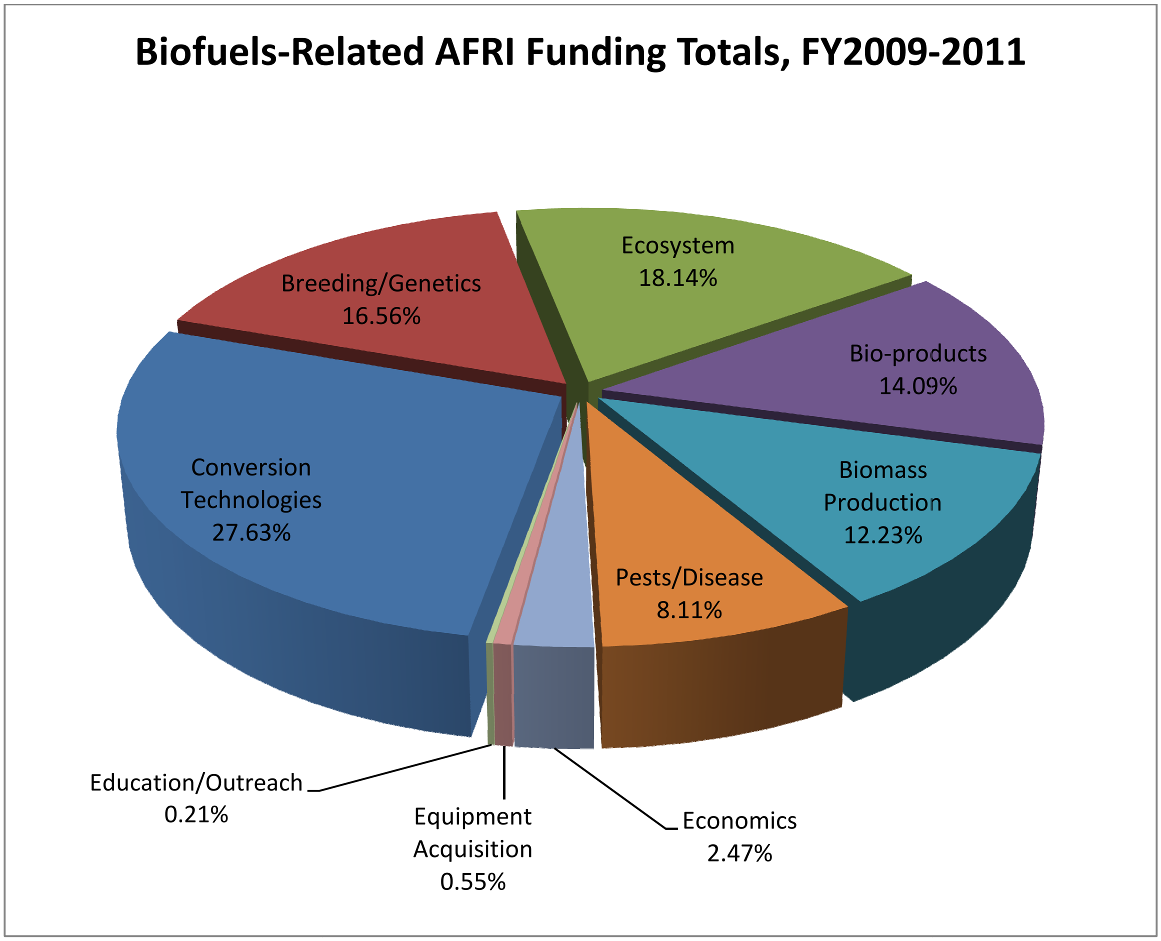

Figure 2.2. Distribution of Biofuels-Related AFRI Awards

Biomass Research and Development Initiative

The Biomass Research and Development Initiative is administered jointly by the USDA and the DOE. The original program was created by the Biomass Research and Development Act of 2000 and was later amended by the Energy Policy Act of 2005 which described four technical areas of emphasis (USDA, 2009a):

- Feedstock Production,
- Product Diversification,

- Technology Development, and
- Technology Analysis.

The awards for FY2002 were the largest of the program, with funds totaling $79.35 million (USDA, 2006). The majority of these funds ($56.49 million) went towards biorefinery development projects, while the remaining $22.86 million were awarded to bioprocessing research projects. The joint-program awarded $23.80 million in FY2003, $26.36 million in FY2004, $12.63 million in FY2005, and $17.49 million in FY2006.

The current initiative was authorized under section 9008 of the 2008 Farm Bill. Technical areas were updated as:

- Feedstock Development,
- Biofuels and Bio-based Product Development, and
- Biofuels Development Analysis.

The initiative provides competitive grants for the research, development, and demonstration of bio-based fuels and products. Funds are awarded to projects that consider life-cycle analysis as well as direct and indirect environmental and economic impacts. These funds can support universities, national laboratories, federal and state research agencies, private sectors, and nonprofit organizations, as well as collaborations of the above (HR 2419, 2008).

Figure 2.3 illustrates the distribution of funding awards from the BRDI. There were no awards in FY2008. It is projected that up to $30 million dollars and up to $40 million dollars will be awarded for FY2011 and FY2012, respectively (USDA, 2009a).

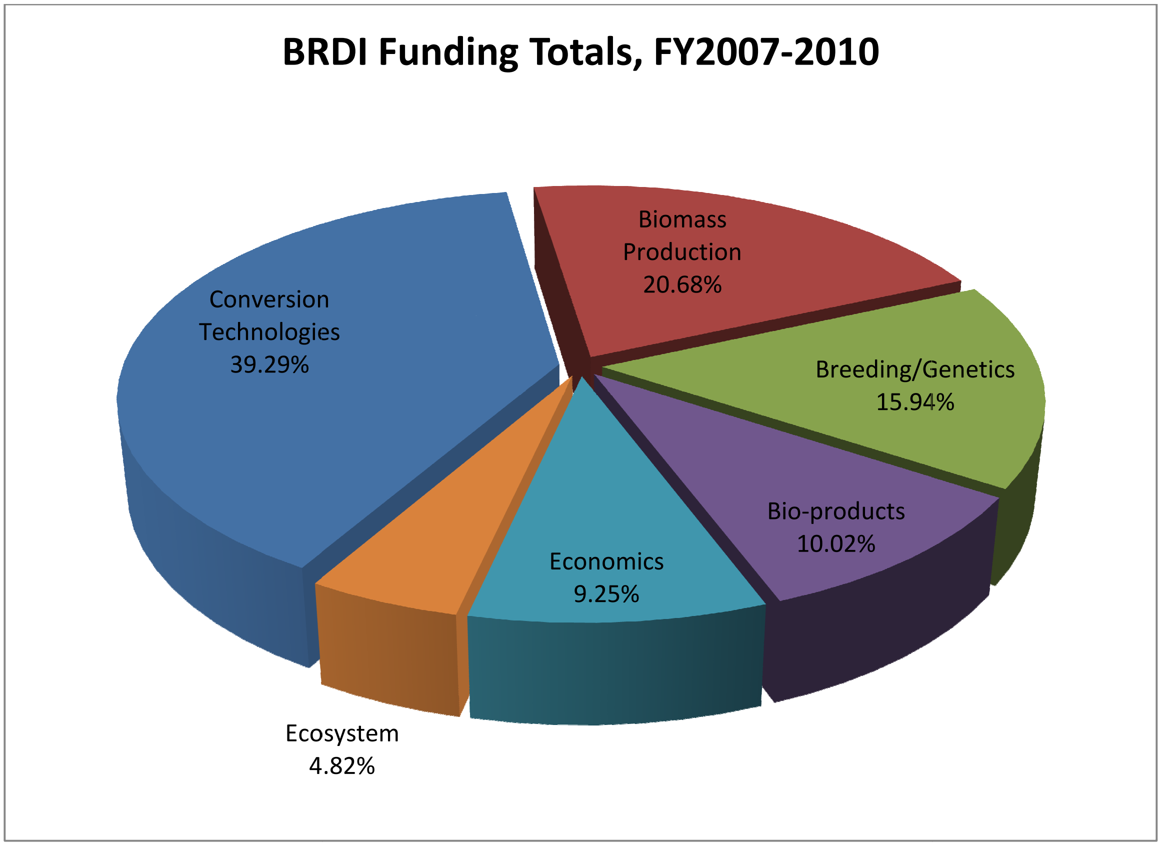

Figure 2.3. Distribution of BRDI Awards

Beginning with the FY2010 awards, USDA and DOE require that projects integrate all three technical areas "to encourage a collaborative problem-solving approach to all studies funded under BRDI, to facilitate formation of consortia, identify and address knowledge gaps, and accelerate the application of science and engineering for the production of sustainable biofuels, bioenergy and biobased products" (DOE and USDA, 2010). This integration could be a great step towards implementing all methods available towards the quality requirements of the biomass for conversion.

Evaluation of Research Funding

Not all funding focuses on quality characteristics. Figure 2.4 shows the distribution of funds for the combined programs for FY2007-2011. It is important to note that:

- FY2011 budget numbers for the Biomass Program are not yet available.
- FY2011 BRDI awards have not yet been announced.
- No FY2008 awards were funded under BRDI.

The first awards under the current AFRI program started in FY2009. By far the greatest portion of funding supports projects that research and develop biofuel conversion technologies. As these technologies mature, the biomass qualities desired will surely be solidified. The second-greatest share supports projects that evaluate or develop economic feasibility of advanced biofuels production. This is to be expected as the technologies for producing advanced biofuels must first be developed and matured; secondly, those technologies must become economically viable if the technological solutions are to be implemented.

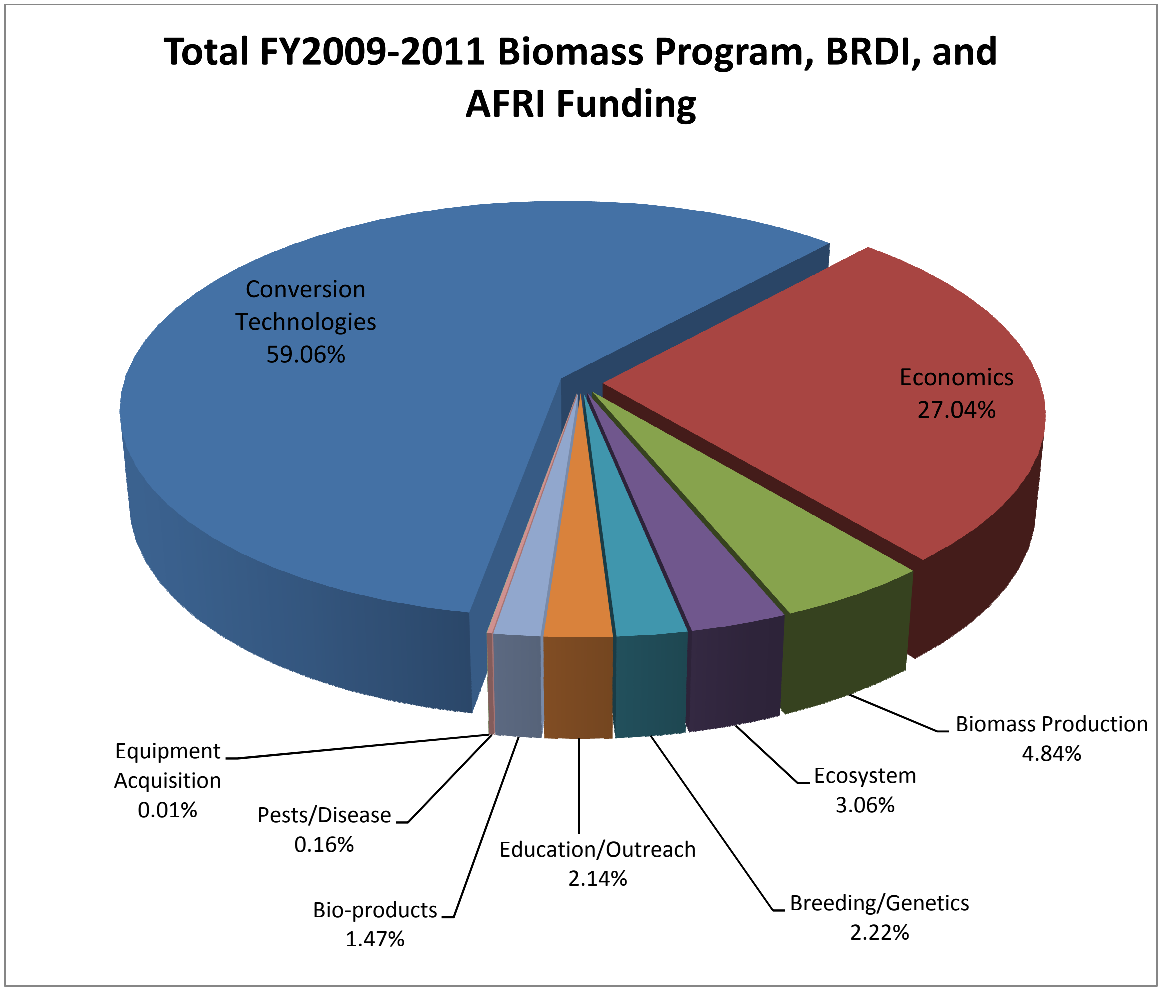

Figure 2.4. Distribution of USDA and DOE Biofuels Funding for FY2007-2011
*FY2011 data not yet available for the Biomass Program or BRDI

OBJECTIVES

The objectives of Part II of this study are to:

- Using the proposal of a current OSU BRDI research project as an example, develop a House of Quality beginning with the CTSs the research describes and create artificial VOC information that would, in theory, have led to the creation of those CTSs.

- Compare the BRDI HOQ to the one constructed from QFD deployment in Part I and analyze how they fit together to determine if the OSU BRDI project, and by extension other biofuels research projects, are focusing on biomass quality requirements of the customer.
- Break down the OSU BRDI project funding by objectives and use it to illustrate how funding is or is not being awarded to proper areas of concern as determined from the QFD deployment HOQ.

METHODS

Developing a House of Quality for the OSU BRDI Project

The HOQ was developed in a backwards fashion, starting with the Customer-to-Satisfaction requirements and ending with the Voice of the Customer statements. The “quality characteristics” objective was analyzed and developed into CTSs that depict the objective’s research. These CTSs are meant to portray engineering requirements that would have been designed to satisfy previously-specified customer requirements. Section 3 of Figure 2.5 will become the BRDI CTSs.

In this case, the customer requirements must be developed from the CTSs. Therefore, artificial customer requirements that describe qualities that the CTSs satisfy were created and entered into the Section 1 of the HOQ. Although these requirements did not come from actual customer quality desires, they are a strong attempt based on the VOC in Part I of the study to correspond to the CTSs.

The steps to build the House of Quality for the OSU BRDI project were implemented into the sections of Figure 2.5 as follows:

- Sections 3 and 4: Engineering objectives were defined in Figure 1.10 to satisfy customer requirements. The directions of improvement were added with arrows indicating to either *increase* or *decrease*.
- Sections 1 and 2: The artificial customer requirements and customer desirability were added.
- Sections 5 and 6: CTS evaluations created relationship values between the CTSs and the customer requirements. The importance scores and importance percentages were calculated as previously described in Part I.
- Section 7: The CTSs were evaluated against each other to determine what correlation, if any at all, those engineering parameters had on each other (negative or positive).
- Section 8: Targets were set in Figure 1.13 along with the assessed difficulty of implementing each CTS.
- Section 9: As previously stated, the planning matrix was not used.

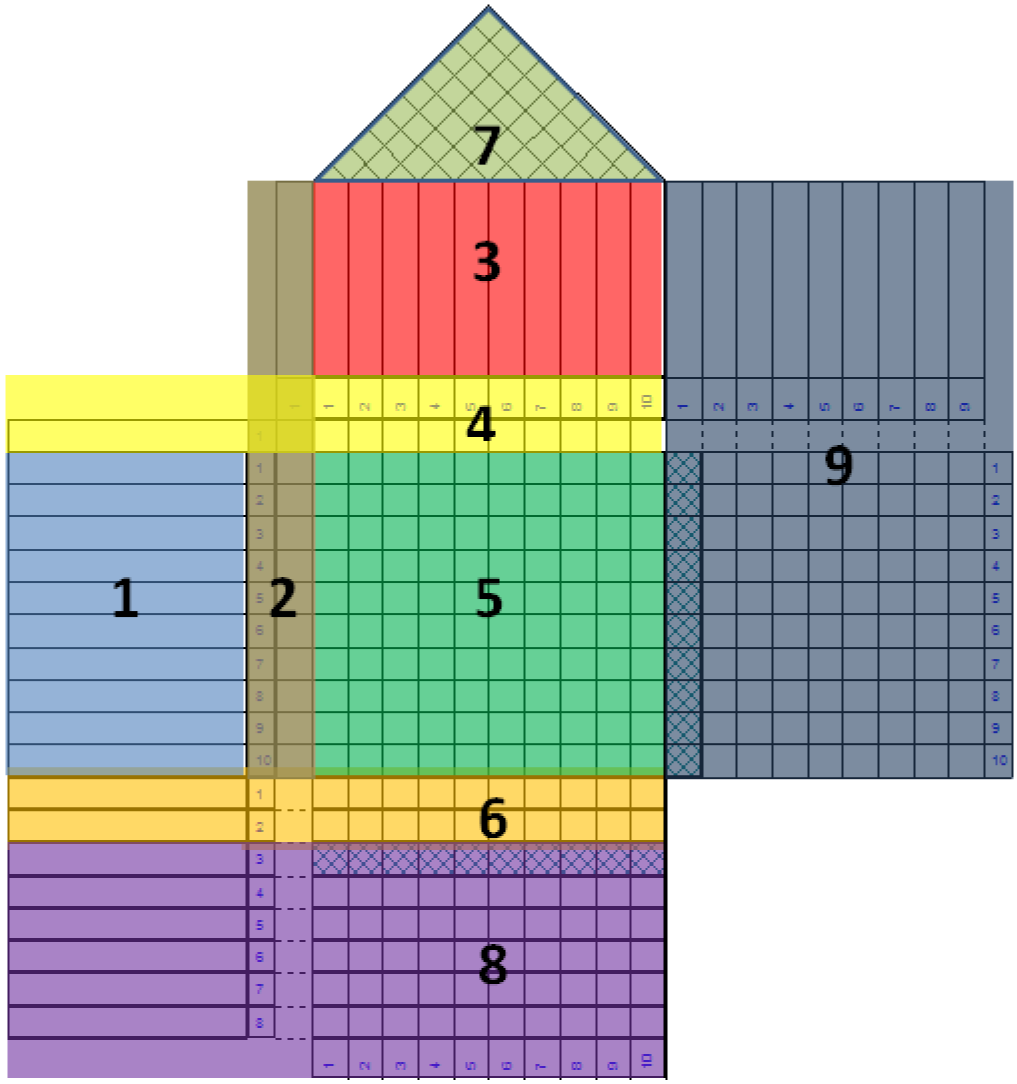

Figure 2.5. Common Contents of a Basic House of Quality

Determining House of Quality Fitment

With the Houses of Quality from both the QFD study and the OSU BRDI project complete, they were compared side-by-side to determine what likenesses and differences existed between them. Table 2.3 (see results below) was created to show VOC overlaps, missed opportunities, and excessive work. Overlaps show what Voice of the Customer quality characteristics from the QFD study were satisfied by the BRDI HOQ. This information illustrates how well the project is addressing customer desires. Missed opportunities identify those VOC characteristics the BRDI HOQ did not satisfy. These statements illustrate where the project objectives fall short of the full VOC requirements. Excessive work shows VOC information from the BRDI project that did not relate to customer desires determined in Part I. This information simply shows where additional time and money is being spent without addressing current VOC quality concerns.

Budget Breakdown

The FY2009 BRDI project funded for Oklahoma State University was used as a reference to determine what customer requirements were currently being satisfied, and which biomass qualities may not be receiving proper attention. With the help of the BRDI project leader, the funding for each objective was broken down so that the proportion of funding used to identify quality characteristics could be determined. Values were calculated to show what percentage of the "quality characteristic" funding investigates VOC quality characteristics and what percentage does not satisfy the VOC criteria.

RESULTS AND DISCUSSION

Developing a House of Quality for the OSU BRDI Project

Table 2.2 shows the quality characteristics addressed by the OSU BRDI project, the CTS parameters derived from these characteristics, and the accompanying VOC information related to those CTSs.

Table 2.2. OSU BRDI Quality Characteristics, CTSs, and VOC Information

Quality	CTS	VOC
Package Size	Package material into 3’x4’x8’ square bales	Must have a large, uniform package size
Package Size	Bale with highest allowable flake content	Must have a dense package
Crop Maturity	Harvest biomass 6 months out of the year	Must be able to harvest multiple seasons
Crop Maturity	Harvest at physiological time for highest energy density	Maximize overall efficiency
Material Handling	Utilize 70% of current crop and bioprocess handling systems	Maximize use of current handling systems
Feedstock Diversity	Harvest and process three different biomass feedstocks	Must not be dependent on a single crop
Biomass Storage	Utilize most cost-effective storage method	Minimize storage costs
Biomass Storage	Use covered storage	Protect stored bales from moisture
Biomass Production	Fully utilize equipment to handle high-tonnages	Maximize production potential
Biomass Production	Dry down to reduce moisture content	Material can’t be too wet

The information from Table 2.2 was entered into a new HOQ for the BRDI project and is shown in Figure 2.6 The CTSs of highest importance for the BRDI would be “harvest at physiological time for highest energy density” and “use covered storage”, while “harvest three different feedstocks” received less importance. This shows that, although the BRDI may cover many aspects of VOC, the conclusion of importance may differ from reality.

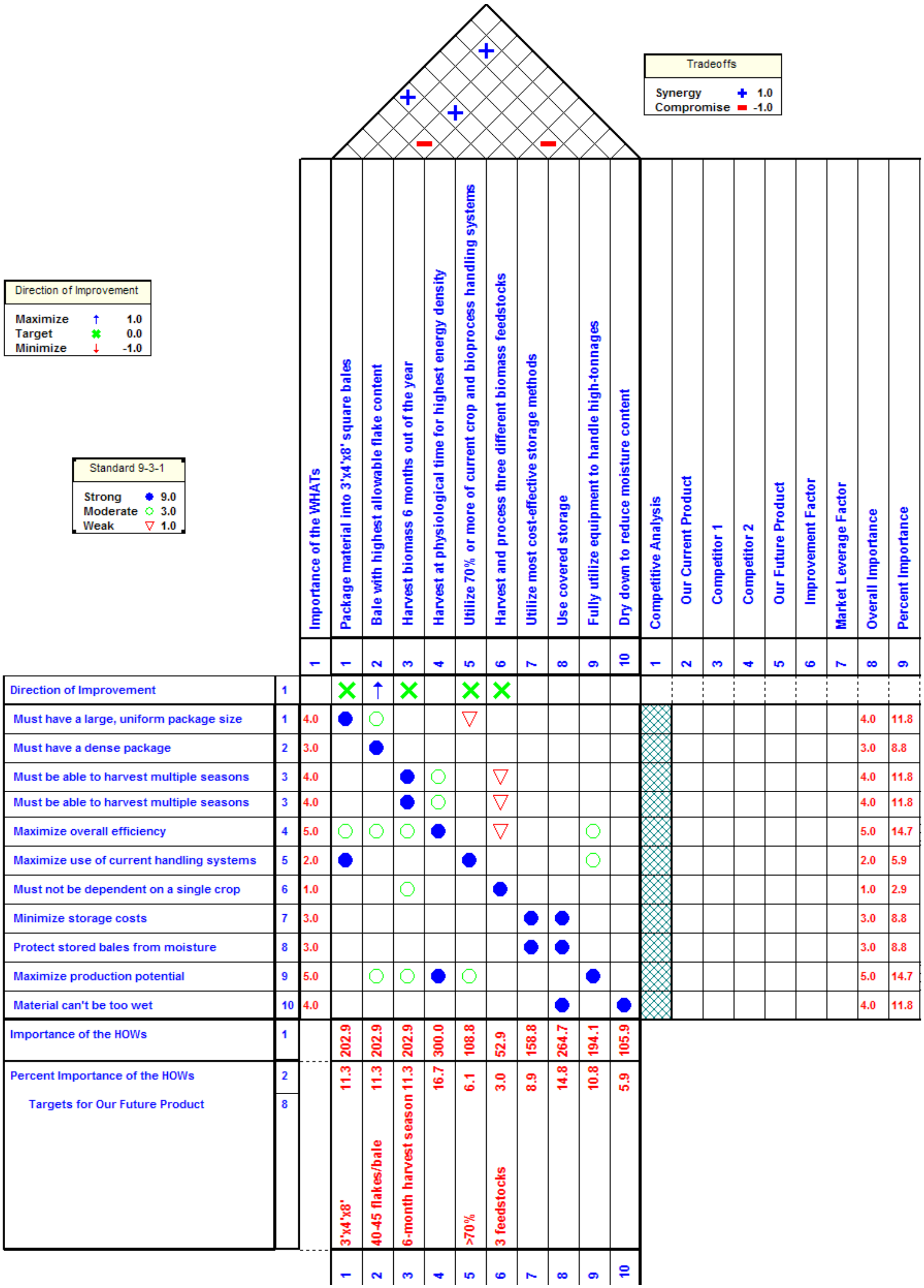

Figure 2.6. Completed HOQ for the OSU BRDI Project

Determination of House of Quality Fitment

Table 2.3 shows the VOC information common to both the deployment study and the BRDI HOQ analysis, the VOC requirements missing from the BRDI HOQ, and the additional quality characteristics described by the BRDI.

Table 2.3. Fitment of the OSU BRDI Quality Objectives

VOC Covered by BRDI	VOC Missing from BRDI	Additional BRDI VOC
Must have a large, uniform package size	Uniform biomass material shape and size	Must be able to harvest multiple seasons
Must have a dense package	Small material size	Maximize use of current handling systems
Material can't be too wet	Very few contaminants	Must not be dependent on a single crop
Protect stored bales from moisture	Low ash content	Minimize storage costs
Maximize production potential (high energy content)		Maximize overall efficiency

Budget Breakdown

The budget for the OSU BRDI project is divided among eight different project objectives as defined in the project proposal (OSU, 2009):

1. Develop best management practices (BMPs) for sustainable **large-scale establishment and production** of feedstock crops.
2. Enhance diversity, productivity, and resiliency through development of **mixed-species** bioenergy production systems.
3. Evaluate and develop **dual-use** production systems for improved resource use efficiency in current and projected climates.

4. Estimate **carbon-sequestration** and climate change mitigation potential of bioenergy crops.
5. Determine potential of bioenergy crops to conserve **surface groundwater resources**.
6. Model **spatial variability** of biomass yields and soil properties in switchgrass fields of differing growing conditions.
7. Identify **quality characteristics** of feedstock, using Abengoa Bioenergy as a customer of reference, to determine at what level designated feedstocks meet quality criteria.
8. Determine **market bid price** (per acre and per ton incentive) for short- and long-term crop and pastureland leases when producers are expected to follow pre-defined BMPs.

The relative percentage of the $4,210,000 funding for each of the eight categories is shown in Figure 2.7. Quality characteristics make up 35% of the total project funding, or $1.46 million. From Table 2.3, half of the items from the quality characteristics objective, or 50% of this $1.46 million (approximately $730,000 if distributed evenly among VOC requirements), is applied to 55.6% of the VOC information identified by the QFD deployment study. As a linear comparison, this particular objective would have only needed $1.31 million ($730,000/55.6%) in funding for the quality characteristics objective to satisfy 100% of the VOC requirements if the entire objective was focused only on the Voice of the Customer.

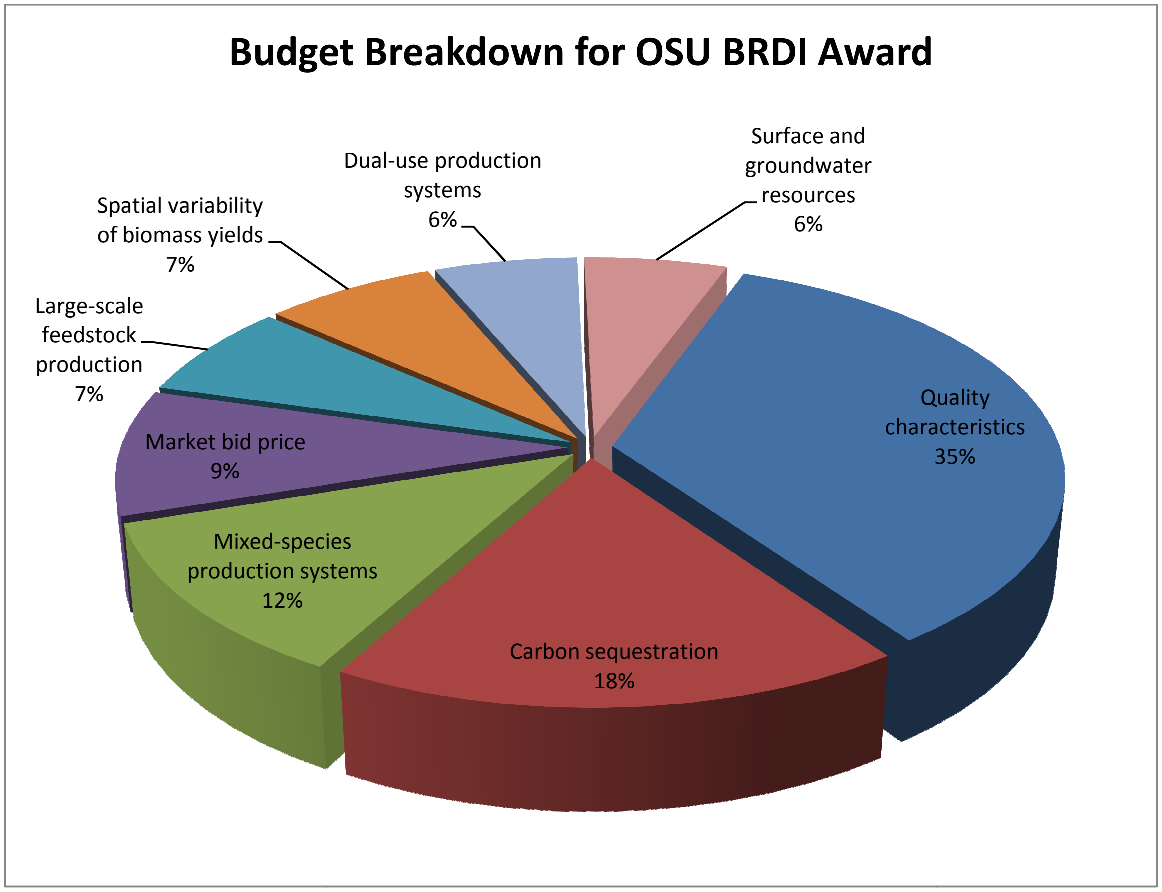

Figure 2.7. OSU Funding Breakdown for BRDI Project Objectives

CONCLUSIONS

Interestingly, biomass production (including harvest, storage, and transportation) can make up 35-65% of the total costs to produce cellulosic ethanol (Fales et al, 2007). Yet funding for biomass production only totaled 5% of the FY2007-2011 awards. For the same period of time, funding for conversion technologies and economics totaled 59% and 27%, respectively, or a combined 86% of funding and awards. These numbers emphasize the importance of reducing production costs. The research funding required to reduce costs can be utilized most effectively when those research projects address concerns, or the VOC, of the biomass users. Improvements in biomass quality, feedstock supply logistics, and equipment processing and handling efficiencies will all contribute to enhanced conversion processes and further improve advanced biofuels production.

Any research project must have a limited, well-defined scope. It cannot necessarily be expected that any one project would be able to focus on every one of the VOC requirements. But current biomass research programs should include quality characteristics as part of an integrated research project, and those quality characteristics must satisfy requirements laid out by the biomass customers, either the biofuels researchers or producers.

With a QFD program fully analyzed and compared against a proposed or current project, the following questions can typically be answered as outlined previously in Table 2.3. It should be noted that this analysis is based solely on the results of the QFD study, given the current information.

- Is our current research too complex, have excessive requirements, etc.?
    - There are no CTSs within the OSU BRDI project that have tighter restrictions or higher requirements than those developed from VOC information gathered from QFD.
- Are technologies mismatched?
    - There are some VOC requirements that the OSU BRDI project is not meeting.

- What projects are unproductive?
    - There are several CTSs the OSU BRDI project proposes that do not effect current VOC information.
- Do we know the desired outcomes?
    - In some cases, the outcomes are merely "utilize", "maximize" or "minimize".

Quality Function Deployment was effectively applied to a biomass supply system while a House of Quality was developed to evaluate a real project within the system. The comparison of a real project with the deployment study of QFD shows that this tool can be used to gather important real-world information from bio-processors when writing biomass research proposals in the future. The BRDI research being conducted by Oklahoma State University includes a quality characteristics objective that meets most of the customer requirements found in the QFD deployment study.

IMPACT STATEMENT

If we assume the OSU BRDI funding is similar to other biomass research projects, then the research community is striving to satisfy quality characteristic requirements but is currently only fulfilling just over half of the customer's needs. Therefore, QFD could be used to augment the research community's development and proposal of projects that satisfy the customers' requirements and help to reduce biomass production and processing costs.

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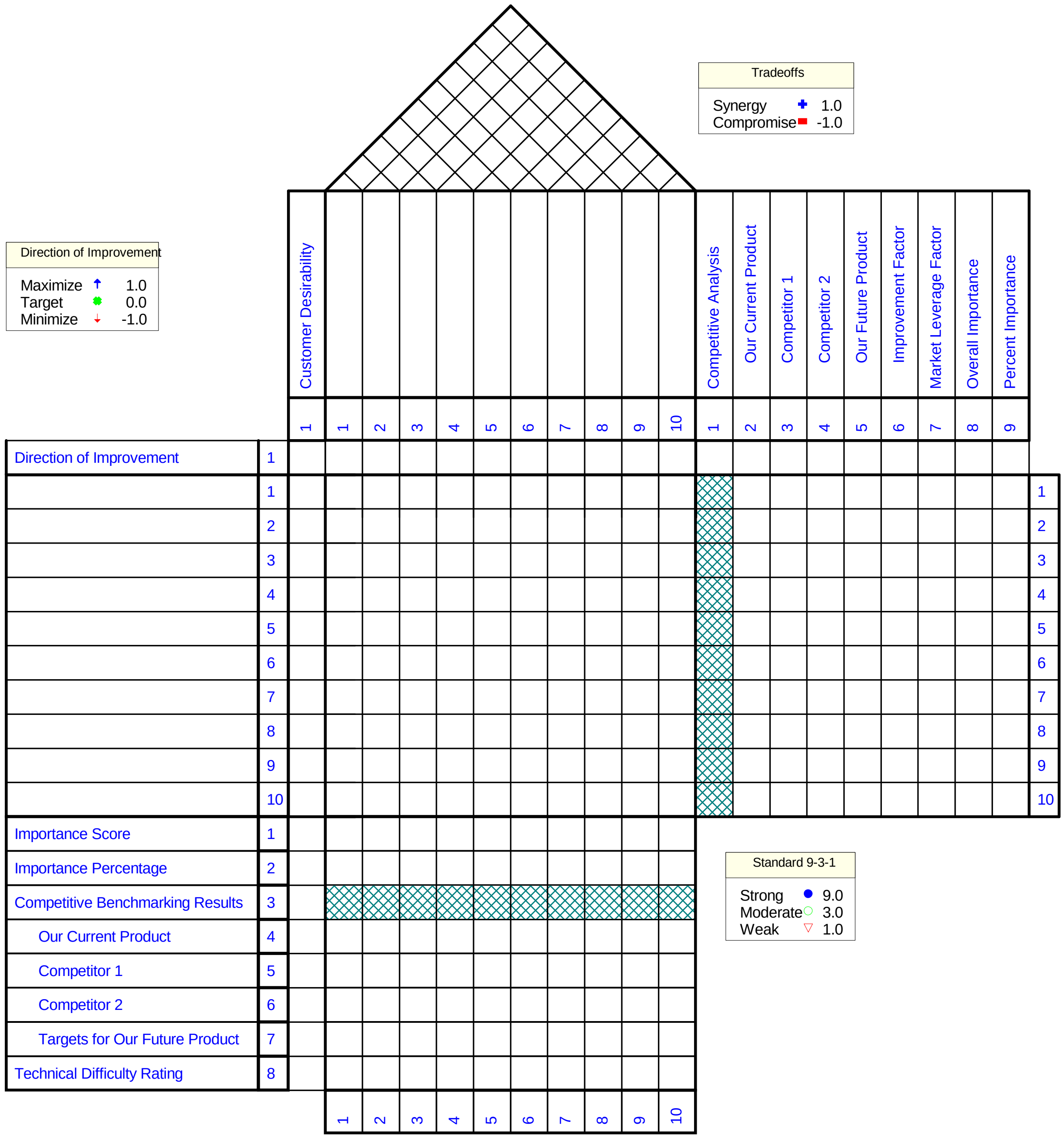
APPENDICES

APPENDIX A: HOUSE OF QUALITY TEMPLATE



APPENDIX B.1: SURVEY 1 – COVER LETTER

Anthony Megel
Biosystems and Agricultural Engineering
Oklahoma State University
214 Ag Hall
Stillwater, OK 74078

Greetings,

Thank you for your willingness to participate in this study, *Development of a Quality Function Deployment (QFD) Matrix for Biofuel Refinery Requirements*. This brief questionnaire should take less than 10 minutes to complete. Your opinion is greatly valued and will be used to better serve the biomass/biofuels industry. Opinions from researchers and industry will be compiled to qualify characteristics of biomass feedstocks as inputs to the refining process.

Note that your responses are confidential and will not be shared with other participants in this study. The information you provide will only be seen by the OSU Bioenergy Postharvest Technology QFD Team. No identifying information is required on this questionnaire. Once the responses are returned, the information will be compiled into an aggregate form to determine an industry overview. I may follow-up with you at a later time for any clarifications or further input. Again, at no time will your responses be shared with other participants.

Thanks again for your willingness to participate. Please contact me at any time if you have any questions or concerns.

Sincerely,

Anthony Megel, Research Engineer
Postharvest Technology
214 Ag Hall
Stillwater, OK 74078
(405) 747-4379
anthony.megel@okstate.edu

APPENDIX B.2: SURVEY 1 – RESEARCHERS

1. In which state do you operate?____________________

2. Please indicate any biomass materials you utilize:

   Switchgrass _____
   Forage sorghum _____
   Prairie grasses _____
   Corn Stover _____
   Other (Please indicate all types) ____

3. What is your primary method of biomass conversion?

   Pyrolysis _____
   Hydrolysis _____
   Gasification _____
   Other (Please specify)____

4. What is your preferred method of pretreatment?____

   Please briefly describe why ____

5. For the following properties, do you have any preferences or dislikes for biomass material?

   Size ____
   Density ____
   Conditioning____
   Additives____
   Other preferences or dislikes ____
   ____

6. Have you identified a minimum preferred energy density?

   Yes_____ No _____________________________________ (If yes, please indicate value and reasoning)
   ____

7. Do you have a preferred moisture content for the biomass? Yes_____ No_____

   Less than 10% _____
   10-25% _____
   25-50% _____
   Greater than 50% _____
   (If yes, please briefly describe the reason) ____

8. Do you have a preferred packaging method for the biomass? Yes_____ No_____

Small square bale _____
Large square bale _____
Large round bale _____
Loose material _____
Other (Please specify) ____
(If yes, please briefly describe the reason) ____

9. How long would you expect biomass material to sit idle before it is processed?

0-3 months _____
3-6 months _____
6-12 months _____
> 12 months _____

10. What is the anticipated average throughput for commercial production plants (amount of feedstock processed per day/month/year)?

____

11. Do you consider any of the following to be a detrimental contaminant to the conversion process?

Twine _____
Plastic _____
Wire _____
Soil _____
Wild animal carcass _____
Other (Please Define) ____

12. Please describe any biomass qualities that would create a price premium or dockage:

____
____

13. Please describe how your biomass is currently supplied: ______________________________

____

14. Please describe any frustrations or complications with the current supply method:_____________

____

15. Please add any additional comments you feel are important at this time ____________________
____
____

APPENDIX B.3: SURVEY 1 – INDUSTRY/REFINERIES

1. In which state do you operate?____________________

2. Please indicate any biomass materials you utilize:

   Switchgrass _____
   Forage sorghum _____
   Prairie grasses _____
   Corn Stover _____
   Other (Please indicate all types) ____

3. What is your primary method of biomass conversion?

   Pyrolysis _____
   Hydrolysis _____
   Gasification _____
   Other (Please specify)____

4. What is your preferred method of pretreatment?____

   Please briefly describe why ____

5. For the following properties, do you have any preferences or dislikes for biomass material?

   Size ____
   Density ____
   Conditioning____
   Additives____
   Other preferences or dislikes ____
   ____

6. Have you identified a minimum preferred energy density?

   Yes_____ No _____________________________________ (If yes, please indicate value and reasoning)
   ____

7. Do you have a preferred moisture content for the biomass? Yes_____ No_____

   Less than 10% _____
   10-25% _____
   25-50% _____
   Greater than 50% _____
   (If yes, please briefly describe the reason) ____

8. Do you have a preferred packaging method for the biomass? Yes_____ No_____

   Small square bale _____
   Large square bale _____
   Large round bale _____
   Loose material _____
   Other (Please specify) ____
   (If yes, please briefly describe the reason) ____

9. How long would you expect biomass material to sit idle before it is processed?

   0-3 months _____
   3-6 months _____
   6-12 months _____
   > 12 months _____

10. What is the anticipated on-site storage capacity? ____

11. What is the anticipated average throughput for commercial production plants?

    ____

12. Do you consider any of the following to be a contaminant to the conversion process?

    Twine _____
    Plastic _____
    Wire _____
    Soil _____
    Wild animal carcass _____
    Other (Please Define) ____

13. Please describe any biomass qualities that would create a price premium or dockage:

    ____
    ____

14. Please describe how your biomass is currently supplied: ____

    ____

15. Please describe any frustrations or complications with the current supply method:________________

    ____

16. Please add any additional comments you feel are important at this time ________________________
    ____

APPENDIX C.1: SURVEY 1 – COVER LETTER

Greetings,

Thank you for your willingness to participate in this study, *Development of a Quality Function Deployment (QFD) Matrix for Biofuel Refinery Requirements*. Your input will help develop a tool that can be used to analyze desired qualities of biomass and develop engineering objectives to enable producers to provide a high-quality supply of biomass to the conversion process.

Some of you may have already seen a similarly described survey that I sent out a couple months ago. The results of that round led to the more thorough survey attached. Note that your responses are confidential and will not be shared with other participants in this study. No identifying information is required on this questionnaire. Please indicate if you are a faculty/post-doctoral researcher or a graduate student.

Please use one page for each conversion process you are involved in. Note that the questions may be similar but apply to specific tasks within the process. Please make sure also to specify any values given with units. Once again, your opinion is greatly valued and will be used to better serve the biomass/biofuels industry.

Sincerely,

Anthony Megel, Research Engineer
Postharvest Technology
214 Ag Hall
Stillwater, OK 74078
(405) 747-4379
anthony.megel@okstate.edu

APPENDIX C.2: SURVEY 2 – COMPLETE INSTRUMENT

Conversion Method (specify one per page)__________________		Faculty or Post-Doc________			Graduate Student________	
Quality Characteristic	**Yes/No**	**Importance Rank (5=highest 1=lowest)**	**Minimum Acceptable**	**Maximum Acceptable**	**Desired Range**	**Comments**
Material Handling (during preprocessing)						Is it crop dependent?
Is there a preferred package size from the field?						
Is there a preferred package density from the field?						
Can the packaged material be too wet?						
Can the packaged material be too dry?						Twine, wrap, plastic bands, pellets, briquets, loose…
Is there a preferred packaging method from the field?						
Must the package be uniform in shape, size, or weight?						
What is the biggest size of package that can be handled?						
Can the package be too hard or too soft?						
Material Utilization (within the conversion process)						Is it crop dependent?
Is there a preferred material size for handling?						
Is there a preferred material density for handling?						
Can the packaged material be too wet?						
Can the packaged material be too dry?						Twine, wrap, plastic bands, pellets, briquets, loose…
Is there a preferred packaging method for handling?						
Must the material be uniform in shape, size, or weight?						
What is the biggest material size that can be handled?						

Quality Characteristic	Yes/No	Importance Rank (5=highest 1=lowest)	Minimum Acceptable	Maximum Acceptable	Desired Range	Comments
Biomass Conversion Technology						
Does the size of the material affect the conversion process?						
Does the density of the material affect the conversion process?						
Can the biomass be too wet?						
Can the biomass be too dry?						
Is there a minimum or preferred energy content?						
Should the ash content be limited?						
Does this process require a pretreatment method? Describe:						
Would pretreatment be helpful to the process? Which method?						
Is there a preferred feedstock for this conversion process?						
Does the stage of crop maturity affect the process?						
Is there a minimum cellulose content?						
Is there a maximum lignin content?						
Does starch content affect the process?						
Does sugar content affect the process?						
Are there any additives that would help the process?						
Are there any contaminants to the conversion process?						
Soil						
Metals						
Plastic						
Twine						
Animal material						
Mold						
Weeds						
Nitrates						
Lignin						
Other						
Other						
Will there be a minimum storage length?						on- or off-site
Will there be a maximum allowable storage length?						on- or off-site

VITA

Anthony J. Megel

Candidate for the Degree of

Master of Science

Thesis: UTILIZING QUALITY FUNCTION DEPLOYMENT TO CREATE A QUALITY REQUIREMENT MATRIX FOR BIOFUEL REFINERY INPUTS VIA VOICE OF CUSTOMER TECHNIQUES

Major Field: Biosystems Engineering

Biographical:

Education:

Completed the requirements for the Master of Science in Biosystems Engineering at Oklahoma State University, Stillwater, Oklahoma in December, 2011.

Completed the requirements for the Bachelor of Science in Mechanical Engineering at West Texas A&M University, Canyon, Texas in May, 2007.

Experience:

West Texas A&M University, Canyon, Texas
Feedlot Research Group, Research Assistant, 2005-2007
Projects: Air quality, agricultural wastes, value-added co-products

Southwest Research Institute, San Antonio, Texas
Engine Design and Development, Engineer, 2007-2009
Projects: Engine design, structural and thermal analysis, computational fluid dynamics, flow testing, test cell installation

Oklahoma State University, Stillwater, Oklahoma
Biosystems and Agricultural Engineering, Research Engineer, 2009-2011
Projects: Systems design and modeling, project design and management, data collection and analysis, field harvest, GPS, machine systems

Professional Memberships:

American Society of Agricultural and Biological Engineers
American Society of Mechanical Engineers
Society of Automotive Engineering

Name: Anthony J. Megel Date of Degree: December, 2011

Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: UTILIZING QUALITY FUNCTION DEPLOYMENT TO CREATE A QUALITY REQUIREMENT MATRIX FOR BIOFUEL REFINERY INPUTS VIA VOICE OF CUSTOMER TECHNIQUES

Pages in Study: 98 Candidate for the Degree of Master of Science

Major Field: Biosystems Engineering

Scope and Method of Study:

The scope of the project involves developing the Quality Function Deployment process for a biomass supply system by gathering Voice of the Customer information and building a House of Quality. The process includes a pilot study, a deployment study, and validation. A current biomass research program is then evaluated and compared against the findings to determine how a current project can use the techniques. The method of study employs the Delphi technique to gather information from biomass supply customers to keep all information confidential and pool the information in a consensus group. In this fashion, no identifying information is gathered; no individuals or the information given can be associated.

Findings and Conclusions:

The use of QFD techniques will play an important role in making qualitative and quantitative determinations that lead to reduced costs of high-quality biofuels. If we assume the OSU BRDI funding is similar to other biomass research projects, then the research community is striving to satisfy quality characteristic requirements but is currently only fulfilling just over half of the customer's needs. Therefore, QFD could be used to help the research community develop and propose projects that satisfy 100% of the customers' requirements and help to reduce biomass production and processing costs.

ADVISER'S APPROVAL: Dr. Carol L. Jones