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# Biofuel Production: Potential Requirements Integration

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## Abstract

Biofuel is one of the promising renewable energy sources that have been getting more attention. Research into biofuel production has found that integrating it into the energy production and distribution infrastructure is a complex problem that has not been completely solved. This paper looks at one aspect of this problem. Improving our understanding of stakeholder requirements to improve production of Fast Pyrolysis Units (FPU) for biofuel production. Previous research has helped identify some stakeholder requirements for FPU production, however there are other potential requirements recommended by Subject Matter Experts (SME). This paper reports on a decision-making process that integrates all the stakeholder and SME requirements to improve FPU manufacturing. The findings show the procedure for integrating the requirements and the results of using this procedure to assess the viability of different size FPUs.

## Keywords
Decision-making, biofuel, pyrolysis, stakeholder requirements

## 1. Introduction

As a promising renewable energy alternative, biofuel have been receiving more attention recently. Fast pyrolysis is a thermochemical process to convert biomass to biofuel (Fawzy & Componation, Biofuel Production: Fast Pyrolysis Units' Manufacturing Infrastructure, 2015 a). Previous studies investigated the manufacturing of the Fast Pyrolysis Unit (FPU). Each study addressed the subject from one or more perspective(s). But very few studies have tried to bring all the aspects of FPU's manufacturing together in a single one decision-making matrix (Fawzy & Componation, 2015 b). Different stakeholder groups should be involved in this decision-making process (Fawzy & Componation, 2014). Where different perspectives and requirements are identified to create the decision-making matrix for the best FPU size that should be manufactured to fit the needs of the different stakeholder groups (Fawzy & Componation, 2015 b; Fawzy & Componation, 2015 c). In previous work, all possible perspectives and requirements those might be related to the decision of FPU size are grouped in one decision matrix. A group of Subject Matter Experts (SMEs) evaluated all these perspectives and requirements. In addition, SMEs evaluated some potential requirements and recommended some of them to be added to the decision matrix of the FPU size. Fawzy and Componation (2015 c) mentioned, "Decision makers often have to make decisions with limited information, especially in new areas such as advanced biofuel production. In order to design valid decision-making support systems to assist decision makers in these situations, a detailed analysis on the available information is required.” The integrated decision matrix should take into account all factors that might influence the decision under different conditions.

This study shows the recommended FPU size out of three alternatives that best fits the stakeholders’ need. This recommendation is done through a systematic decision-making approach. The decision matrix is created to cover all the different aspects included in FPU manufacturing. This research also provides better understanding of the problem to create enhanced approach for the decision of manufacturing, placement, and right sizing of FPUs for biofuel production. Finally, a sensitivity analysis was conducted to determine the recommendation robustness. The use of the Logical Decisions ® helped in having the enhanced approach and more detailed sensitivity analysis. We believe that additional information in the future might influence the current decision. The current recommended size is done based on the conceptual assessment of FPUs' sizes. Similar to biofuel production, FPU manufacturing, this process is also applicable for a big range of other open-ended engineering problems. In other words, the used decision-making processes in this study could be applied for other renewable energy problems with limited information and multi-stakeholders involvement.

## 2. Study objective

This study investigates the effect of integrating the SME requirements with the stakeholder requirements of the FPU manufacturing to improve this decision-making process.

## 3. Literature review

Previous research identified an optimal FPU size with minimal cost of biofuel production (Wright & Brown, 2007). However, the capital cost of this optimal size is too large for investors, which lead to high investment risk (Fawzy & Componation, 2015 b). In general, limited work has been done on optimization biofuel production process (Larasati, Liu, & Epplin, 2012). FPU size is studied in recent research throughout three suggested alternatives according to unit consumption of biomass per day. The first suggested unit size is called big unit that consumes at least 2000 ton per day (tpd) of biomass. The second alternative is a medium size unit that consumes between 200 and 500 tpd of biomass. The tired suggested unit size is called small unit, mobile unit that consumes at most 50 tpd (Fawzy & Componation, 2015 b; Fawzy & Componation, 2015 c).

This recent work identified eighteen requirements as the decision factors, stakeholder requirements, for the unit’s manufacturing. From the SMEs evaluation, the small unit is recommended as the best fit for the stakeholders’ requirements. In addition, the SMEs recommended ten additional requirements to be added to this decision matrix (Fawzy & Componation, 2015 c).

The unit compatibility with existing infrastructure is one of the recommended requirements to be added to the decision matrix. Seven out of the ten SMEs evaluated this requirement as an important factor. On the other hand, none of the previous research, with the exception of Fawzy & Componation (2015 b), mentioned this as a factor in biofuel production decision.

Safety is recommended by the SMEs as one of the most important perspectives of biofuel production decision. Even though it was mentioned only three times in previous biofuel production research between 1996 and 2014, at least 60% of the SMEs evaluated the suggested safety requirement as highly important requirements in Fawzy & Componation (2015 b). Sixty percent of the SMEs evaluated the Safety improvement as a highly important requirement for the FPU size selection. In addition, 80% of them assessed the unit size effects of danger on facilities as highly important requirement for the decision. Also, the relationship between the unit size and the probability of an accident due to safety was weighed as highly important requirement by 70% of the SMEs. Finally, both the workers and the society safety were evaluated as highly important requirements. Therefore, in this study all these five requirements related to safety are considered as SME requirements in the integrated decision matrix (Fawzy & Componation, 2015 b).

Manufacturing process improvement such as continual and/ continues improvement, the easiness of technology updates for new units, and the effect of learning curve are also three highly important requirement according to the SMEs recommendation (Fawzy & Componation, 2015 b).

Even though the number of offered jobs is considered as one of the stakeholder requirements of the FPU manufacturing, only 20% of SMEs evaluated it as highly important requirement. Alternatively, SMEs recommended the long-term jobs requirement to be considered specifically in this decision matrix as a highly important requirement. Where 60% of the SMEs evaluated the long-term jobs requirement as highly important one. Therefore, this requirement will be added to the integrated decision matrix in this study. But this SME requirement is clearly derived from the stakeholder requirement, number of offered jobs. Therefore, we decided to remove the stakeholder requirement, number of offered jobs from the integrated matrix. Then we rerun the model as part of the sensitivity analysis to see the recommendation robustness (Fawzy & Componation, 2015 b).

The sensitivity analysis is important to examine the result robustness under several conditions. Michalopoulos and his colleges (2011) argue that "positive and negative assessments of biofuel development are strongly influenced by the differences in perspective (focus) between different stakeholder clusters." In the sensitivity analysis for this study the relationship between the best two alternatives is also studied to know more about the recommendation strength.

## 4. Methodology

This study modifies a previous decision-making process on FPU manufacturing. From the previous research, SMEs recommended some potential requirements to be added to the stakeholder requirements (Fawzy & Componation, 2015 c). These potential requirements are added to the decision-making process by modifying the previous model that was created for the same process (Fawzy & Componation, 2015 c). This model is designed using Microsoft Excel 2013.

Then, the model is redesigned for the sensitivity analysis and more result analysis using the Logical Decision ® V7.2. In the Logical Decision® model all the requirements are listed and connected directly to the main goal.

For weighing the potential requirements, the SME evaluated each requirement using a three-level score (high, medium, low). Then, the average evaluation is calculated using Equation 1.

$$\text{Requirement's weight} = \frac{3*(\#of\ SMEs1)+2*(\#of\ SMEs2)+1*(\#of\ SMEs3)}{Total\ number\ of\ SMEs} \quad (1)$$

Where:

SMEs 1: is the group of those who weighted the requirement's importance as high.

SMEs 2: is the group of those who weighted the requirement's importance as medium.

SMEs 3: is the group of those who weighted the requirement's importance as low.

In all analysis the big FPU size that consumes at least 2000 tpd of biomass is used as the analysis base. For data collection the Pugh concept is used to compare the potential requirements between the three alternatives using the score line shown in table 1.

**Table 2.** Code for Requirements' Evaluation Assessment Scores

| The code: | Big advantage | Advantage | Same | Disadvantage | Big disadvantage |
|---|---|---|---|---|---|
| | 2 | 1 | 0 | -1 | -2 |

Then, the average value of the SMEs evaluation for each requirement is calculated using Equation 2.

$$\text{Average requirement's scores} = \frac{\sum_{i=1}^{10} SME_i}{Total\ number\ of\ SMEs} \quad (2)$$

Next, each requirement's score at each alternative is calculated by using Equation 3.

$$\text{Requirement's score} = \text{Avg. of requirement's scores} * \text{Requirement's weight} \quad (3)$$

After that, the integrated decision matrix is created by adding these scores to the initial matrix, which have the stakeholder requirements scores as shown in Figure 1. Finally, alternatives scores are calculated by using Equation 4.

$$\text{FPU's score} = \sum_{i=1}^{28}(requirement_i\ scores) \qquad (4)$$

Then, the scores are normalized using Equation 5.

$$\text{Normalized score} = \sum_{i=1}^{28}\left(\frac{\text{Requirement}_i\text{ weight}}{\sum_{i=1}^{28}\text{Requirement}_i\text{ weight}}\right) * \text{ Requirement's score} \qquad (5)$$

For the second model, these normalized data were entered into the developed model using direct entry function in the Logical Decisions software ® V7.2. The model was then run and utilities were calculated from the software using functions called Single-measure Utility Functions (SUFs), which convert measure levels to utilities.

The last step in this study is the sensitivity analysis. Part of it is done through the modification and recalculation of the scores in the Excel model using equations 4 and 5. The other part of the sensitivity analysis is done via the Logical Decisions software ®. This type of analysis investigates the difference between the best two alternatives at each requirement of the both the stakeholder and SME ones.

## 5. Result and discussion

The big FPU size is the study base of evaluation. Therefore, all the requirements values at this alternative are equal to zero. As a result, the total score for this alternative is equal to zero. The two other alternatives were evaluated by SMEs at each of the potential requirements. The potential requirements were added to the stakeholder requirements. The model is created using two software programs. The first model is done using Microsoft Excel 2013 ®. The second model is done using the Logical Decision ® V7.2.

As a result for the first Excel model (Figure 1), the small FPU size that consumes at most 50 tpd of biomass received a total score equal to 16.7240. The medium FPU size that consumes between 200 and 500 tpd of biomass has a total score equal to 9.1297. By normalizing the scores using equation 5 we can see that the small unit is better than the big alternative by approximately 24%. Moreover, the medium unit size is better than the big alternative by 13.09%.

After analyzing the scores of the model shown in Figure 1, FPU with a capacity of 50 tpd was found as the best selection because it has the highest final score. These results match the result of the previous study which was conducted on the stakeholder requirements only (Fawzy & Componation, 2015 c). In addition, FPU with a capacity between 200 – 500 tpd became the second best alternative according to its final score whereas FPU with a capacity of at least 2000 tpd was ranked as the last option. The normalized values and the improvement percentages between the three alternatives help the decision makers to make the right decision. This helps them to discuss the result and decide if it is worth to work on making the small FPU size or not.

| Requirements | Priorities | | | | Requirement weight | Alternatives (Facility size) evaluations average | | | Alternatives (Facility size) The weighted Scores | | | Requirement weight | Alternatives (Facility size) The weighted Scores | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Pugh Concept – feedstock inputs tpd | | | Pugh Concept – feedstock inputs tpd | | | | Pugh Concept – feedstock inputs tpd | | |
| | H | M | L | no answer | | ≥ 2000 tpd (base) | 200 – 500 tpd | ≤ 50 tpd | ≥ 2000 tpd (base) | 200 – 500 tpd | ≤ 50 tpd | | ≥ 2000 tpd (base) | 200 – 500 tpd | ≤ 50 tpd |
| CO2 emission | 4 | 4 | 2 | 0 | 2.20 | 0 | 0.1111 | -0.4444 | 0 | 0.2444 | -0.9778 | 0.032 | 0 | 0.0035 | -0.0140 |
| Resources saving | 5 | 4 | 1 | 0 | 2.40 | 0 | 0.1250 | -0.1250 | 0 | 0.3000 | -0.3000 | 0.034 | 0 | 0.0043 | -0.0043 |
| Design cost | 4 | 4 | 2 | 0 | 2.20 | 0 | 0.3333 | 0.7778 | 0 | 0.7333 | 1.7111 | 0.032 | 0 | 0.0105 | 0.0245 |
| Capital cost (including Equipment) | 9 | 1 | 0 | 0 | 2.90 | 0 | -0.7000 | -1.3000 | 0 | -2.0300 | -3.7700 | 0.042 | 0 | -0.0291 | -0.0541 |
| Equipment cost | 7 | 2 | 1 | 0 | 2.60 | 0 | -0.5000 | -1.2000 | 0 | -1.3000 | -3.1200 | 0.037 | 0 | -0.0186 | -0.0447 |
| Labor cost | 2 | 2 | 6 | 0 | 1.60 | 0 | -0.7000 | -1.1000 | 0 | -1.1200 | -1.7600 | 0.023 | 0 | -0.0161 | -0.0252 |
| Production cost in the facility | 7 | 3 | 0 | 0 | 2.70 | 0 | -0.4444 | -0.8889 | 0 | -1.2000 | -2.4000 | 0.039 | 0 | -0.0172 | -0.0344 |
| Materials cost (feedstock) | 7 | 3 | 0 | 0 | 2.70 | 0 | 0.4000 | 0.7000 | 0 | 1.0800 | 1.8900 | 0.039 | 0 | 0.0155 | 0.0271 |
| Transportation cost for feedstock | 5 | 2 | 2 | 1 | 2.33 | 0 | 1.1111 | 2.0000 | 0 | 2.5926 | 4.6667 | 0.033 | 0 | 0.0372 | 0.0669 |
| Response to market & policy uncertainties | 7 | 2 | 1 | 0 | 2.60 | 0 | 0.5556 | 0.8889 | 0 | 1.4444 | 2.3111 | 0.037 | 0 | 0.0207 | 0.0331 |
| Storage cost for Feedstock | 3 | 5 | 2 | 0 | 2.10 | 0 | 0.5000 | 0.9000 | 0 | 1.0500 | 1.8900 | 0.030 | 0 | 0.0151 | 0.0271 |
| Storage cost for produced biofuel | 4 | 1 | 4 | 1 | 2.00 | 0 | -0.2222 | -0.3333 | 0 | -0.4444 | -0.6667 | 0.029 | 0 | -0.0064 | -0.0096 |
| Annual investments (maintenumnce) | 6 | 4 | 0 | 0 | 2.60 | 0 | 0.3000 | 0.1000 | 0 | 0.7800 | 0.2600 | 0.037 | 0 | 0.0112 | 0.0037 |
| Energy saving | 3 | 6 | 1 | 0 | 2.20 | 0 | -0.5000 | -0.7000 | 0 | -1.1000 | -1.5400 | 0.032 | 0 | -0.0158 | -0.0221 |
| Biomass availability (now) | 6 | 3 | 1 | 0 | 2.50 | 0 | 0.8000 | 1.4000 | 0 | 2.0000 | 3.5000 | 0.036 | 0 | 0.0287 | 0.0502 |
| Operation efficiency | 4 | 6 | 0 | 0 | 2.40 | 0 | -0.5000 | -0.6000 | 0 | -1.2000 | -1.4400 | 0.034 | 0 | -0.0172 | -0.0207 |
| Policy & regulations | 6 | 4 | 0 | 0 | 2.60 | 0 | -0.1250 | 0.2500 | 0 | -0.3250 | 0.6500 | 0.037 | 0 | -0.0047 | 0.0093 |
| Number of jobs | 2 | 4 | 4 | 0 | 1.80 | 0 | 1.0000 | 1.7000 | 0 | 1.8000 | 3.0600 | 0.026 | 0 | 0.0258 | 0.0439 |
| Compatible with existing infrastructure | 7 | 2 | 0 | 1 | 2.78 | 0 | 0.1111 | 0.3333 | 0 | 0.3086 | 0.9259 | 0.040 | 0 | 0.0044 | 0.0133 |
| Safety improvement | 6 | 4 | 0 | 0 | 2.60 | 0 | -0.6667 | -1.0000 | 0 | -1.7333 | -2.6000 | 0.037 | 0 | -0.0249 | -0.0373 |
| Effects of danger on facilities | 8 | 2 | 0 | 0 | 2.80 | 0 | 0.5000 | 0.8750 | 0 | 1.4000 | 2.4500 | 0.040 | 0 | 0.0201 | 0.0351 |
| Probability of an accident (due to safety) | 7 | 2 | 1 | 0 | 2.60 | 0 | -0.6250 | -0.8750 | 0 | -1.6250 | -2.2750 | 0.037 | 0 | -0.0233 | -0.0326 |
| People / workers safety (safety of employees) | 8 | 1 | 1 | 0 | 2.70 | 0 | 0.2857 | 0.4286 | 0 | 0.7714 | 1.1571 | 0.039 | 0 | 0.0111 | 0.0166 |
| Safety of the community (society) | 8 | 2 | 0 | 0 | 2.80 | 0 | 0.8571 | 1.4286 | 0 | 2.4000 | 4.0000 | 0.040 | 0 | 0.0344 | 0.0574 |
| Continual / Continues improvement | 8 | 1 | 0 | 1 | 2.89 | 0 | 0.1250 | 0.3750 | 0 | 0.3611 | 1.0833 | 0.041 | 0 | 0.0052 | 0.0155 |
| Ease of technology updates (for new units) | 6 | 3 | 0 | 1 | 2.67 | 0 | 0.1429 | 0.4286 | 0 | 0.3810 | 1.1429 | 0.038 | 0 | 0.0055 | 0.0164 |
| Effect of learning carve | 9 | 1 | 0 | 0 | 2.90 | 0 | 0.4444 | 1.0000 | 0 | 1.2889 | 2.9000 | 0.042 | 0 | 0.0185 | 0.0416 |
| Long-term jobs | 6 | 2 | 1 | 1 | 2.56 | 0 | 0.8889 | 1.5556 | 0 | 2.2716 | 3.9753 | 0.037 | 0 | 0.0326 | 0.0570 |
| | | | | | | | FINAL SCORES: | | 0 | 9.1297 | 16.7240 | 1.00 | 0 | 0.1309 | 0.2399 |

**Figure 1.** Excel Model

As a result for the second model (Figure 2), the small FPU size that consumes at most 50 tpd of biomass received a utility equal to 0.567. The medium FPU size that consumes between 200 and 500 tpd of biomass has a utility equal to 0.533. The big FPU size that consumes at least 2000 tpd received a utility equal to 0.500. Thus, the small unit is the best alternative even though all the utility values are close to each other. Figure 2 presents the three alternatives ranking and utilities for the model based on the SMEs requirements analysis. Even though the utilities for the best two alternatives in this study have different values from the utilities from the study of the stakeholder requirements only (Fawzy & Componation, 2015 c), the rank of the three alternatives is still the same. Moreover, we can see that the gap between the best two alternative increases when adding the SME requirement to the decision matrix.

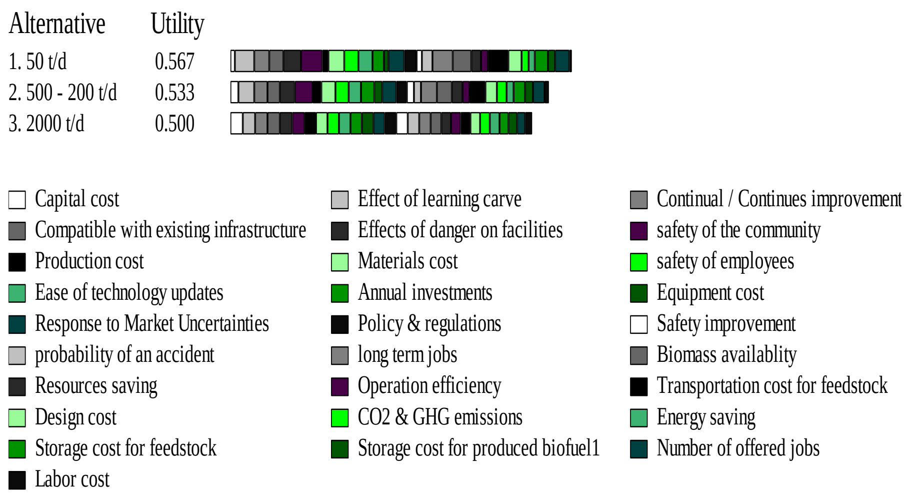


**Figure 2.** Final Utilities for the Alternatives Analysis from the Logical Decisions Model

## 6. Sensitivity Analysis

To examine the decision robustness, sensitivity analysis was conducted. Sensitivity analysis helps to identify the dominant requirement(s). In addition, this analysis helps to know under which condition(s) the decision will change. Besides, sensitivity analysis shows the best alternative under different situations, if exists.

For this study two parts of sensitivity analysis were conducted. The first part is a tornado chart that applied on the best two FPUs alternatives for all the 28 requirements using Logical Decisions ® V7.2. Figure 3 shows the tornado chart to investigate the differences between the small FPU size and the medium FPU size. From this figure we can see that all the 28 requirements are ranked according to the gap or difference value between the two alternatives. The transportation cost for the feedstock has the biggest gap between the two alternatives. As shown in Figure 3 the medium size of FPUs, due to its distribution, is worse than the small FPU size in transportation cost of raw material. On the other hand, safety of employees, operation efficiency, and storage cost of the produced biofuel are the requirements with minimal difference between the two FPU sizes.


**Figure 3.** Sensitivity Analysis on Best Two FPUs' Sizes

The second part of the sensitivity analysis is done using the Excel model. As mentioned in the literature review, the SME requirement, long-term jobs, is clearly derived from the stakeholder requirement and number of offered jobs. Therefore, we decided to remove one of the duplicate requirements from the integrated matrix; we decided to remove the least important requirement of the two. Then we rerun the model as part of the sensitivity analysis to see the recommendation robustness. The stakeholder requirement, number of offered jobs, has less importance than the SME requirement, long-term jobs based on the SMEs evaluation. Therefore, we decided to remove the requirement of number of offered jobs. Figure 4 shows the analysis of the 27 requirements after removing the requirement of number of offered jobs. As shown in Figure 4, FPU with a capacity of 50 tpd is still the best selection with total score equal to 13.6640. This result matches the result of the original model. FPU with a capacity between 200 – 500 tpd is still the second best alternative with final score equal to 7.3297. In the same way, FPU with a capacity of at least 2000 tpd is ranked as the last option with total score equal to 0. By normalizing the scores using equation 5 we can see that the small unit is better than the big alternative by 20.12%. Moreover, the medium unit size is better than the big alternative by 10.79%.

| Requirements | Priorities | | | | Requirement weight | Alternatives (Facility size) evaluations average | | | Alternatives (Facility size) The weighted Scores | | | Requirement weight | Alternatives (Facility size) The weighted Scores | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Pugh Concept – feedstock inputs tpd | | | Pugh Concept – feedstock inputs tpd | | | | Pugh Concept – feedstock inputs tpd | | |
| | H | M | L | no answer | | ≥ 2000 tpd (base) | 200 – 500 tpd | ≤ 50 tpd | ≥ 2000 tpd (base) | 200 – 500 tpd | ≤ 50 tpd | | ≥ 2000 tpd (base) | 200 – 500 tpd | ≤ 50 tpd |
| CO2 emission | 4 | 4 | 2 | 0 | 2.20 | 0 | 0.1111 | -0.4444 | 0 | 0.2444 | -0.9778 | 0.032 | 0 | 0.0036 | -0.0144 |
| Resources saving | 5 | 4 | 1 | 0 | 2.40 | 0 | 0.1250 | -0.1250 | 0 | 0.3000 | -0.3000 | 0.035 | 0 | 0.0044 | -0.0044 |
| Design cost | 4 | 4 | 2 | 0 | 2.20 | 0 | 0.3333 | 0.7778 | 0 | 0.7333 | 1.7111 | 0.032 | 0 | 0.0108 | 0.0252 |
| Capital cost (including Equipment) | 9 | 1 | 0 | 0 | 2.90 | 0 | -0.7000 | -1.3000 | 0 | -2.0300 | -3.7700 | 0.043 | 0 | -0.0299 | -0.0555 |
| Equipment cost | 7 | 2 | 1 | 0 | 2.60 | 0 | -0.5000 | -1.2000 | 0 | -1.3000 | -3.1200 | 0.038 | 0 | -0.0191 | -0.0459 |
| Labor cost | 2 | 2 | 6 | 0 | 1.60 | 0 | -0.7000 | -1.1000 | 0 | -1.1200 | -1.7600 | 0.024 | 0 | -0.0165 | -0.0259 |
| Production cost in the facility | 7 | 3 | 0 | 0 | 2.70 | 0 | -0.4444 | -0.8889 | 0 | -1.2000 | -2.4000 | 0.040 | 0 | -0.0177 | -0.0353 |
| Materials cost (feedstock) | 7 | 3 | 0 | 0 | 2.70 | 0 | 0.4000 | 0.7000 | 0 | 1.0800 | 1.8900 | 0.040 | 0 | 0.0159 | 0.0278 |
| Transportation cost for feedstock | 5 | 2 | 2 | 1 | 2.33 | 0 | 1.1111 | 2.0000 | 0 | 2.5926 | 4.6667 | 0.034 | 0 | 0.0382 | 0.0687 |
| Response to market & policy uncertainties | 7 | 2 | 1 | 0 | 2.60 | 0 | 0.5556 | 0.8889 | 0 | 1.4444 | 2.3111 | 0.038 | 0 | 0.0213 | 0.0340 |
| Storage cost for Feedstock | 3 | 5 | 2 | 0 | 2.10 | 0 | 0.5000 | 0.9000 | 0 | 1.0500 | 1.8900 | 0.031 | 0 | 0.0155 | 0.0278 |
| Storage cost for produced biofuel | 4 | 1 | 4 | 1 | 2.00 | 0 | -0.2222 | -0.3333 | 0 | -0.4444 | -0.6667 | 0.029 | 0 | -0.0065 | -0.0098 |
| Annual investments (maintenumnce) | 6 | 4 | 0 | 0 | 2.60 | 0 | 0.3000 | 0.1000 | 0 | 0.7800 | 0.2600 | 0.038 | 0 | 0.0115 | 0.0038 |
| Energy saving | 3 | 6 | 1 | 0 | 2.20 | 0 | -0.5000 | -0.7000 | 0 | -1.1000 | -1.5400 | 0.032 | 0 | -0.0162 | -0.0227 |
| Biomass availability (now) | 6 | 3 | 1 | 0 | 2.50 | 0 | 0.8000 | 1.4000 | 0 | 2.0000 | 3.5000 | 0.037 | 0 | 0.0294 | 0.0515 |
| Operation efficiency | 4 | 6 | 0 | 0 | 2.40 | 0 | -0.5000 | -0.6000 | 0 | -1.2000 | -1.4400 | 0.035 | 0 | -0.0177 | -0.0212 |
| Policy & regulations | 6 | 4 | 0 | 0 | 2.60 | 0 | -0.1250 | 0.2500 | 0 | -0.3250 | 0.6500 | 0.038 | 0 | -0.0048 | 0.0096 |
| Compatible with existing infrastructure | 7 | 2 | 0 | 1 | 2.78 | 0 | 0.1111 | 0.3333 | 0 | 0.3086 | 0.9259 | 0.041 | 0 | 0.0045 | 0.0136 |
| Safety improvement | 6 | 4 | 0 | 0 | 2.60 | 0 | -0.6667 | -1.0000 | 0 | -1.7333 | -2.6000 | 0.038 | 0 | -0.0255 | -0.0383 |
| Effects of danger on facilities | 8 | 2 | 0 | 0 | 2.80 | 0 | 0.5000 | 0.8750 | 0 | 1.4000 | 2.4500 | 0.041 | 0 | 0.0206 | 0.0361 |
| probability of an accident (due to safety) | 7 | 2 | 1 | 0 | 2.60 | 0 | -0.6250 | -0.8750 | 0 | -1.6250 | -2.2750 | 0.038 | 0 | -0.0239 | -0.0335 |
| people / workers safety (safety of employees) | 8 | 1 | 1 | 0 | 2.70 | 0 | 0.2857 | 0.4286 | 0 | 0.7714 | 1.1571 | 0.040 | 0 | 0.0114 | 0.0170 |
| Safety of the community (society) | 8 | 2 | 0 | 0 | 2.80 | 0 | 0.8571 | 1.4286 | 0 | 2.4000 | 4.0000 | 0.041 | 0 | 0.0353 | 0.0589 |
| Continual / Continues improvement | 8 | 1 | 0 | 1 | 2.89 | 0 | 0.1250 | 0.3750 | 0 | 0.3611 | 1.0833 | 0.043 | 0 | 0.0053 | 0.0159 |
| Ease of technology updates (for new units) | 6 | 3 | 0 | 1 | 2.67 | 0 | 0.1429 | 0.4286 | 0 | 0.3810 | 1.1429 | 0.039 | 0 | 0.0056 | 0.0168 |
| Effect of learning carve | 9 | 1 | 0 | 0 | 2.90 | 0 | 0.4444 | 1.0000 | 0 | 1.2889 | 2.9000 | 0.043 | 0 | 0.0190 | 0.0427 |
| Long-term jobs | 6 | 2 | 1 | 1 | 2.56 | 0 | 0.8889 | 1.5556 | 0 | 2.2716 | 3.9753 | 0.038 | 0 | 0.0334 | 0.0585 |
| | | | | | | | FINAL SCORES: | | 0 | 7.3297 | 13.6640 | 1.00 | 0 | 0.1079 | 0.2012 |

**Figure 4.** Modified Excel Model

## 7. Conclusion

In conclusion, three FPU sizes were examined to select the best fit for the stakeholder and SME requirements. Two integrated models were created for making this decision. As result, the small FPU size that consumes at most 50 tpd of biomass is the best alternative even though all the scores and utility values are close to each other for the three alternatives. The medium FPUs size is recommended as the second best alternative. This integrated decision matrix helps the decision makers to discuss in details all the aspects of the decision. This result supports the argument "bigger is not always better." This encourages engineers to think small in design and manufacturing perceptions as Dahlgren and his colleague (2013) recommended.

In the future, this study could be replicated by having a bigger group of SME. With the appearance of more information about the FPU manufacturing, would benefit a replication of this study. Finally, the used models for this decision-making process could be also used for similar renewable energy decisions while further sensitivity analysis will also help to understand the problem better.

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## Biography

**Dr. Mostafa F. Fawzy** is a researcher working on decision-making research for complex problems. He received his Ph.D in Industrial Engineering at Iowa State University. His is interested in the development of decision-making support systems for complex problems such as energy manufacturing. Moreover, his research interests include lean principles applications, strategic planning, and performance enhancement. Dr. Fawzy worked in the consulting field as a development engineer and project manager for five years in the Jeddah Municipality and two consulting offices.

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