Supply Chain Management Model of Wood Biomass Producing Hydrogen Fuel for Malaysia's Electricity Industry

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***Abstract*— Green energy is becoming an important aspect of every country in the world toward energy security by reducing dependence on imported fossil fuel import and enhancing better life quality by living in the healthy environment. This article analyses available literature as an approach toward determining physical flow's characteristic of waste wood biomass in high scale plantation toward producing gas fuel for electricity using gasification technique. The aim of this study is to develop a conceptual supply chain management model of syngas fuel from wood waste biomass using direct gasification conversion technology. Literature are reviewed based on energy security, Malaysia's energy mix, Biomass supply chain management and processing technology. This paper uses the theoretical model of transportation (Lumsden, 2006) and the function of the terminal (Hulten, 1997) for research purpose. The theoretical framework used to answer the research questions are Supply Chain Operations Reference (SCOR) framework and Sustainable strategy development in supply chain management framework. To incorporate biomass unique properties, Biomass Element Life Cycle Analysis (BELCA) which is a novel technique develop used to understand the behaviour of biomass supply based on biomass's elements.**

***Keywords*—** *Green Supply Chain, Natural-Resource, Biomass, Green electricity, Hydrogen fuel*

1. Introduction

Energy security able to be achieved by ensuring continuous availability, affordability and acceptability of resource supply that able to reduce shortage risk in meeting energy demand [2, 5, 6, 7, 8, 9]. With the recent growth in Malaysia oil and gas production and consumption, Malaysia has experienced high growth in greenhouse gas emission level due to CO_2 emitted. Natural gas with 50% in power generation mixes become the major fuel source for electricity supply in Malaysia followed by coal. In order to full fill electricity demand, Malaysia decides to enhance the import coal volume and renewable energy development based on solar, biomass and biogas. Currently, a research division of Tenaga Nasional Berhad is working on gasification technology for coal to produce syngas to be used in gas turbine [1]. However, coal releases a high quantity of CO_2 to the atmosphere which causes pollution [10].

The problems facing with biomass to energy production are ensuring supply sustainability and sustainable power generation. These are due to fluctuation in source supply, handling and technology efficiency [33]. However, a transition of power generation of non-renewable energy toward domination of renewable energy sources is more than shifting in technology for fuel conversion but there are also transaction of supply chain management, social acceptance and government policy [15]. Currently, Malaysia power green energy industry is facing barriers regarding the movement of energy through a place, time and existing energy infrastructures due to lack of knowledge on technologies and effective supply chain management [33] in addition to varies properties of biomasses [21]. This paper will consider waste wood biomass from various type of high plantation industry in Malaysia.

The following questions are to be answered in this paper: (1) What are characteristics involved in the physical flow of waste wood biomass toward energy production supply chain management model? (2) How gasification of biomass can enhance energy efficiency in comparison to current practice. This conceptual paper has very significant impact because it will explore factors that involve

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in supply chain management model of waste wood biomass in Malaysia perspective starting from the raw source until meeting the electricity customers. This paper will analyse syngas supply chain management that included pre-processing stage. Pre-processing considered are shredding technique that uses to cut wood into small pieces and a mixture chamber of all type of wood input.

2. Literature Review

Energy is a source of power that is produced through networks of companies using different technologies to transform a variety of energy carriers such as solid, gaseous, liquid and kinetic energy to consumable energy entities such as electricity, heat and vehicle fuel used in industry and households.

Different country will take different security action toward their energy security based on production, storage, demand, energy forecasting and fuel switching. Fuel switching technically is limited to oil products in order to get the same calorific value. Development of laboratory and process technology make others fuel source considerable [3]. Malaysia government decide to apply cost effective means and diversifying Malaysia's fuel source supply portfolio [32].

These decisions in hope will support economic development and enhance manufacturing activities [1, 11, 41]. Those sources are not limited to non-renewable energy, but also alternatives and renewable energy such as solar, waste, wind, nuclear and hydrogen.

Malaysia energy source for electricity are gas (53.8%), coal (35.3%), hydro (10.3%), distillate (0.6%) and MFO (0.04%). Peak demand for electricity in peninsular Malaysia is 16,901 MW and in 2015 is 16,562 MW [11]. In parallel with world urge toward a healthier environment, Malaysia government had established Sustainable Energy Development Authority (SEDA) and introduce fit in tariff (FiT) system to enhance development on renewable energy [12].

Malaysia starts producing biodiesel in 2013 with a production of 6,000 bbl/day and a significant quantity of ethanol develop from laboratories work by local researchers from universities [3]. Malaysia currently marketed significant amount of palm oil biomass for biodiesel production to Singapore and Europe [1, 12]. The final products of biomass process will differ depend on biomass type, conversion technology and source's environment [23].

Less of knowledge in biomass potential, handling, logistics and technology lead toward less effort taken to discover biomass fuel potential especially hard to gain society's confident and support [22]. Malaysian has been a boon with the equatorial monsoon and fertile soil which make this country suitable for many types of plantation such as rubber, palm oil, cocoa, coconut, durian, rambutan and mango which produce waste wood source [13]. As an example, Malaysia palm oil industry spans roughly 5.23 Million hectares of fields and generates US$ 255 million per year [14].

2.1 Biomass Supply Chain Management

Study on supply chain management and research on valued supply chain is essential to review and appraise any industry's operational and strategically objective. It could be for product or service industry [39]. Based on supply chain perspective, decisions have to be put together regarding on type of feedstock, processing plant, distribution system and demand profile [22]. In achieving gas supply security, factors involve are diversify gas sources, supply quantity, storage capacity, transportation, production, demand, infrastructure, economic, technical risks, environmental, regulation and political [15, 26]. The complexity of producing biomass energy creates demand for simulation approach in combination with effective supply chain management [12].

The significant effort had been taking on biomass to fuel production either in production quality or economical effective conversion technique. Recently, study related to logistic initiate due to concerning inability of biomass source to provide continuous raw material supply, power production sustainability and profitability [28]. Biomass supply chain management consists of a harvester, collectors, storage, pre-processing facilities and transportation. The value chain of biomass supply will reduce cost and high responsiveness. However, it is difficult to achieve both ultimate aims. In order to minimize cost, cheapest transportation medium has been selected. With the aim to minimize the responsive time, fastest transportation mode has been chosen that often induce extra cost. Besides, two criteria mentioned, others criteria should be considered in making those decisions such as routes condition, weather and political issues [40].

Biomass supply chain will prioritize local supplier because one of biomass fuel implementation objective is to reduce dependence on import fuel source. Local supplier development able to reduce cost and improve international company access to local customer market in energy produces from renewable sources. The international firm will consider investing in renewable energy for energy projects when several hustle initiatives taking on improving local biomass supplier. Strategies in strengthening local sourcing will reduce supply risk with low volume supply through high supplier number. Supplier development initiative will reduce the risk of the transaction in specific investment [34].

The kind of supply chain studied and the constraints handled are strongly influenced by the national and local policies concerning bioenergy, agricultural practices, and land management. These differences explain that there is no ubiquitous model of biomass supply chain in the current state of research [21, 22]. After a wealth of strategic models with highly aggregated data, more and more models address the tactical decision level and a multi-period horizon. However, the way they handle harvesting and transport equipment is still limited, even if some recent progress can be observed [23].

There are different characteristic have to be consider when deal with different type of biomass such as sources (crops, urban waste, or forest biomass), different plants, and different forms of the same biomass (e.g., switchgrass in bales or pellets). No author discusses the possibility of value, at varying degrees, different parts of the same plant, such as seeds, straw and chaff for colza. Most models handling biomass degradations use a very simple method, a loss coefficient per period spent in stock. Only a few works have gone further and show that an accurate modeling of degradations is not trivial [24, 37].

Still few authors consider nodes dedicated to storage, pre- processing, or pre-conversion between harvesting areas and biorefineries. When such nodes are dealt with, they most often represent on-farm storages [25] and simple pretreatments like baling. Such facilities should be modeled more precisely. For instance, pre-processing facilities have input and output storages and the silos of a centralized storage can be used by different products over time [24, 26].

2.2 Modelling

A quantitative model is suggested to deal with large scattered and various type biomass supplier in order to evaluate resource need, optimized the resource required, environmental impact, procurement associated and mass energy heat balance through the production process [24].

Most models use to present biomass supply chain are lack generality and scalability. They impose a temporal granularity such as a one-year horizon subdivided in months, a spatial granularity such as a geographic area divided into elementary squares using a GIS and a fixed network structure. The integration into real application programs is rarely discussed, for instance, the way of gathering, structuring and storing a large amount of required data.

It is also found that the model with its equations can only be defined by the designer of the model. Most users cannot change it easily, given the special skills required. However, it seems possible and more interesting to let the user describe his network in a flexible way, for example in graphical form, and then to generate automatically the mathematical model from this description. The proposed models are either strategic or tactical, with or without facility location decisions. It is possible to offer the user a choice of complementary models, for instance, one with facilities already placed and one when the sites are not yet determined [24].

Original and interesting optimization problems are raised by the design of biomass supply chains. Compared with industrial logistics, many input nodes scattered over vast territories have to continuously supply output nodes with biomass produced by slow-growing crops. These characteristics may lead to large-scale models, especially when detailed operations or multi-period are considered. Rapid advances in computers and optimization software, a growing number of publications propose nowadays more and more realistic supply chain models.

However, several trends, current limitations, and possible research directions can be detected by the analysis of literature [35]. Current researchers studies are related to the characteristics of supply chains, the modelling issues and the algorithms used to solve the models.

2.3 Comparison between direct fired and gasification techniques

Currently, most of the biomass-to-energy practitioner use direct burning [27] with various enhancement technologies such as co-firing, stoker boilers and fluidized bed boilers. Coal fired plant can produce up to 100 to 1,000 MW while biomass power system currently is typically producing up to 50 MW [27]. A boiler used to burn dried biomass to generate high-pressure steam that used to power a steam turbine toward electricity production. Otherwise, to produce process heat, space heating, or space cooling, medium pressure and temperature rate will be used in the boiler. Co-firing involves substituting biomass for a portion of the coal in an existing power plant boiler [12].

It is the most economic upcoming decision for introducing new biomass power plant because no major plant modification needed within current existing plant equipment. Considering coal and biomass co-firing will enhance profitability by produce fuel with less CO_2, SO_2, NO_X, and zero certain other air emissions and less capital cost especially on building a new biomass power plant [29, 30]. The efficient combustion of solid biomass material such as wood chip or wood pellets depends on the temperature in the combustion chamber, an adequate supply of oxygen and the fuel remaining in the combustion chamber so that it burns completely [27]. A modern wood chip or pellet boiler will be set up in such a way so as to ensure that these conditions are met. This is done by controlling the speed of the fan that draws the air into the combustion chamber. During combustion, the fuel goes through four distinct stages. Initially, the fuel is dried, and then the intense heat in the combustion chamber causes the fuel to begin to decompose. As it decomposes the products produced react with the nitrogen and oxygen in the air to create gasses including.

Two type of firing is direct firing and indirect firing. The externally or indirectly firing of the gas turbine means that the combustion chamber is not directly connected to the gas turbine [27].

Biomass gasification systems function by controllable heat and air amounts where solid phase biomass will break down into flammable gas phase. Among specific technologies on gasification technique is fixed bed gasifiers and fluidized bed gasifiers. The product is Syngas which hydrogen as the sale gas that can be cleaned, filtered and burn in a gas turbine either using combine cycle or simple system. Syngas can be fired in reciprocating engines, microturbines, Stirling engines, or fuel cells for a small amount of power produce needed. Nowadays, gasification of biomass by-products is being used hugely for the paper industry and pulp. The practitioners improvise chemical recovery toward producing higher process steam and electricity efficiencies with less capital cost than conventional technologies [31].

2.4 Summary

Based on previous work in energy security by considering mix energy of renewable and non-renewable energy supply chain management, it can be concluded that non-renewable energy has established a firm structure of supply chain management. Otherwise, there are very fundamental studies being conducted on renewable energy supply chain management especially on biomass fuel. Recently, biomass related researches focus on laboratory experiment methods by considering on maximize biogas volume production based on processing technology and raw material species.

Researchers try to adapt current supply chain management structure on biomass fuel, however because of variation in biomass properties, more consideration need to be addressed for efficient production and economical supply chain management. A number of researches on biomass supply chain management conducted, yet there are lots of lacking criteria that need to improve such as in harvesting scheduling, storage and pre-treatment.

Biomass has a variation of properties in term of chemical and physical due to the type of biomass, location origin, cultivation technique and handling, more specific attention should be given to biomass supply chain management for different category of biomass. Categorization can be performed based on elements, conversion energy, product desire and others.

Carbon emission has the bigger impact on the economy due to several issues such as health and environment amendment which make natural gas becoming huge potential to dominate market energy mix in coming decades for heat, electricity and vehicles. Biomass extraction with gasification technique will enhance syngas production volume for electricity usage to support natural gas consumption. Finding from scholars will become a reference for Malaysia's policy makers to make policies on renewable energy management of solar, biogas, biomass, nuclear and hydro.

This study will fill the gap in finding the effective biomass to the syngas production supply chain management model framework. As the fully desired product is syngas fuel, gasification energy conversion technique for fuel production is suggested to produce electricity compared to direct burning that is currently practiced most. The chain will include pre-treatment and storage capabilities to ensure continuously electricity power supply.

After sufficient literature been reviewed on current biomass supply chain management practiced, this study will construct a method for the syngas production from wood plantation industry for sustainable green electricity production in Peninsular Malaysia which will be explained in next chapter, methodology.

3. Methodology

Using literature and theoretical models that best explain on physical movement of supply management are Model of Transportation Network by based on Ref. [17] and Function of the Terminal based on Ref. [16] plus with Biomass Element Life Cycle Analysis (BELCA) model.

The theoretical frameworks that relate to research issues used are Supply Chain Operations Reference (SCOR) framework and Sustainable Strategy Development in Supply Chain Management.

3.1 Theoretical model

A node refers to a geographical position of activities involve within the supply chain system from supply origin until meet customers. The nodes could be supply sources, a location of storage, transshipment or processing of goods or terminate point.

Based on figure 1, Ref. [16] stated that by appointed nodes, a system must be able to bridge gaps between types of transportation. The gaps of product's physical flow will be closer in term of frequency, capacity and time consuming.

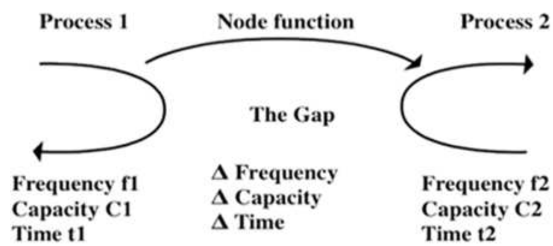

Figure 1. The function of the terminal

Referring to figure 2, transportation defines a network of links and nodes. Links which appointed by arrow used to connect nodes. Vehicles and vessels with infrastructure either through water, air or land are used to transfer goods. The model can be applied for physical, information or management transfer [17].

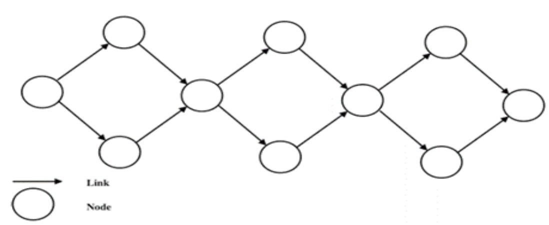

Figure 2. A model of transportation

This wood biomass to energy via gasification can to some extent be compared and adapt from two above explained models on nodes and links.

Still few authors consider nodes dedicated to storage, pre-processing or pre-conversion between harvesting areas and bio refineries. When such nodes are dealt with, they most often represent on-farm storages [25] and simple pre-treatment like baling. Such facilities should be modeled more precisely. For instance, pre-processing facilities have input and output storages and the silos of a centralized storage can be used by different products over time [23, 26].

Nodes in the model consist of plantation area, collecting station, pre-processing sections, storage, gasification plant, the gas turbine for electricity produce and substations for electricity transmission line. Transshipment will be considered due to change in product's physical phase that is from solid to gas.

3.2 Theoretical framework

The theoretical framework is a summary based on theories developed that relate to research issues that become a structure which able to support the research. It will identify a strategy for research questions, perspective to use, variables involve, analysis, understanding and interpretation of the findings.

The Supply Chain Operations Reference (SCOR) framework established by APICS Supply Chain Council known as the leading practicable world supply chain framework that relates workforce skills, practices, business process and performance analysis into a structure. This framework implementation aims to increase system implementation efficiency, accelerate inventory return and support organizational learning. Supply Chain Operations Reference (SCOR) framework provide the complete elements involve in supply chain management starting from supplier until product or service meet the customer and any rare cases on return.

The framework covers all aspect in between supply and customers which include plan supply chain, plan source, the plan makes, plan to deliver and plan a return as shown in figure 3 below [34].

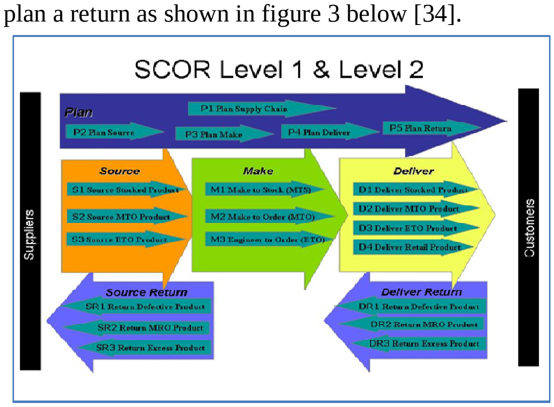

Figure 3. Research domains related to SSCM in SCOR framework

Sustainable strategy development in supply chain management framework provides analysis scope in external and/or internal context of supply chain management as shown in figure 4.

External context identifies an effect of selected environmental factors otherwise internal context will consider component account in the suggest supply chain network. Sustainability will be derived from economy and business management perspective. Analysis and development based on research methodology that differentiates into a common index and respective index of industrial sections to find economic value from its own supply chain practices. The analysis should identify the exact research area, define the sustainability based on indicators and identify implementation strategies. Application area might be in leadership, innovation, integration, improvement and compliance area [34].

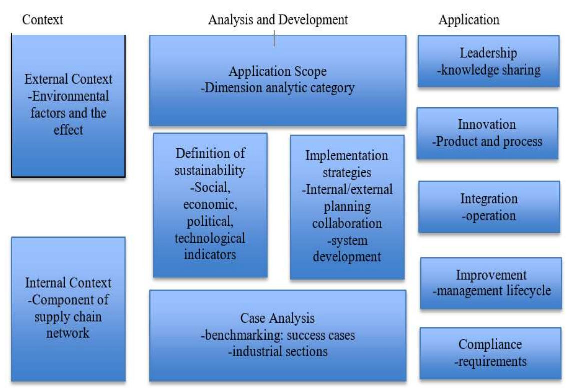

Figure 4. Framework for sustainable strategy development in supply chain management

Figure 5 show a novel approach that takes into account biomass system life cycle and element classification to be integrated into a supply chain model. BELCA model can be used by biomass supply chain practitioner to understand the biomass behaviour in planning biomass supply chain system to maximize profit. When several types of biomass are taken into account, they come from different sources (crops, urban waste, or forest biomass), from different plants, or from different forms of the same biomass such as switch grass in bales or pellets [23].

No author discusses the possibility to value at varying degrees and different parts of the same plant such as seeds, straw and chaff for colza. Most models handling biomass degradations use a very simple method that is a loss coefficient per period spent in stock. Only some works have gone further and show that an accurate modelling of degradations is important [24].

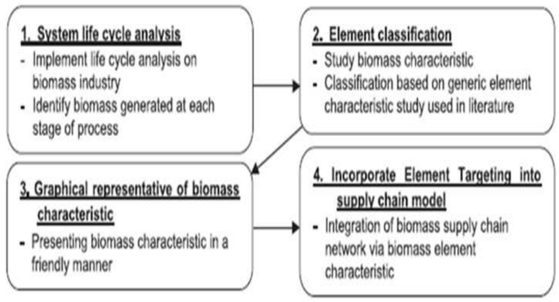

Figure 5. BELCA approach

BELCA model shows the necessity in recognise the correct type of waste biomass characteristic and conversion technology use to enhance the productivity and life cycle of the industry.

It is identified that this wood biomass toward hydrogen fuel supply chain management for electricity production supply chain management model, need three main phase that is a source collection, energy production and product deliver. Sustainable strategy development in supply chain management framework suggests various dimensions in a sustainable perspective to be added in the model.

A suggested model able to represent material flow, financial flow and information flow. Physical flow involved material flow starting from biomass source until electricity received by the customer.

4. Discussion

Optimization models are almost all solved with commercial solvers, which are too general to fully exploit their mathematical structure and display running times growing very quickly with the size of the chain and the number of integer variables. This explains that models are still relatively small or need large CPU times, especially those dealing with tactical decisions and various constraints. Treating larger instances or more detailed models requires developing dedicated algorithms, such as decomposition methods, relaxation techniques, and metaheuristics.

This need is critical for models which spends too much time in multiple calls to a solver, as it is common in stochastic programming (scenarios evaluation) or multi-objective optimization (ε-constraint method). Some approaches which have already demonstrated their efficiency in industrial logistics have not yet been applied to biomass such as multiobjective genetic algorithms like NSGA-II and simulation-based optimization. Simulation and stochastic optimization are the main tools to determine robust solutions, such as little affected by uncertainties.

Robust optimization, a recent discipline which does not rely on probability distributions, could be useful. Finally, we are struck by the predominance of authors working in university departments or laboratories devoted to agricultural engineering [37], wood science [36], chemistry [31], or energy [27].

Although many ideas from industrial logistics could be transposed to biomass supply chains, very few authors are affiliated to industrial engineering departments. Computer scientists and operational research specialists, who could optimize the formulations or design algorithms for large cases, are even rarer. Composing multi-disciplinary research teams is a key success factor in designing accurate and realistic models for biomass supply chains [38].

Liner programming models is a method that currently practices identifying the greatest setup in bioenergy supply chain to illustrate the nodes, depots and arcs. Depot represents biomass source based on biomass type meanwhile node can represent production facilities such as pre-treatment, storage, conversion plant and power plant. Arcs will represent transportation routes of biomass starting from source’s location until meet targeted demand [16, 17]. Digital map is necessary when linear programming model will be developing based on Geographical Information System (GIS) data. GIS data can be manipulated to find the best location for each node for efficient and economical bio energy network model within a specific area such as province or country. The network structures based on the study objective such as sustainable energy production and identify minimum transportation cost [22].

4.1 Future research

This conceptual paper is a start in making understanding and link of wood waste biomass, gasification technology, syngas production and supply chain management in Malaysia perspective. Investigation in every aspect of supply chain management dimensions has to be observed by initiate with energy efficiency calculation either in term of profitability or usability.

Further exploration of harvesting, pre-treatment, conversion technology, transportation and distribution network should be carried out. The ultimate aim is to create a valid supply chain management model for waste wood biomass to syngas fuel energy production through gasification techniques in order to support gas electricity production among Malaysian users.

5. Conclusion

Characteristics involve in the physical flow of waste wood biomass toward energy are source locations, warehouse storage for raw material, shredding plant for pre-processing, gasification plant, gas power plant and electricity customers. However, a different type of transportation needed for logistics between each node due to product phase that is either solid or gas. Gasification of biomass can enhance energy efficiency in comparison to direct burning because it can enhance chemical recovery, generate process steam at higher efficiencies, lower capital cost and lower operation cost due to less heat need.

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