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# SUPPLY CHAIN EFFICIENCY OF ENVIRONMENTALLY FRIENDLY MICROALGAE-BASED BIODIESEL PRODUCTION

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***Abstract:*** *Environmentally friendly algae-based biodiesel production includes biofuel extraction that represents a technological process which inflicts minimal damage to the environment or does not harm it. Biodiesel that is almost completely based on renewable resources can be utilized as one of the most promising biofuels, and it is environmentally safer than petrol-diesel for several reasons such as: 1. Microalgae have high photosynthesis efficiency and can grow very fast; 2. Microalgae can be cultivated without occupying farmlands, and thus it is possible to reduce the potential damage to the agricultural ecosystem and the traditional food webs; 3. Fresh water is not essential and nutrients can be supplied by wastewater and CO2 by gas combustion during cultivation; 4. Microalgae can be collected very quickly, obviously accelerating the biodiesel production process; 5. The property of their uniform cell structure with no bark, stems, branches or leaves make the commercial production attractive, thus making the operation and control of reproduction conditions much more practical; 6. The general properties as well as the physical biodiesel fuel properties from algae oil (e.g. density, viscosity, acid value, heating value, etc.) are comparable to those of fuel diesel. This paper investigates in detail this option presenting advantages, but also existing limits and gaps. Undoubtedly, incorporating the principles of supply-chain management enabled by information technology (IT) systems to support these processes is a more effective and efficient option to enhance the efficiency of algae-based biodiesel production.*

***Key words:*** *microalgae-based biodiesel production, supply-chain management, simulation game, IT integration*

# 1 INTRODUCTION

There has been ever-increasing demand for diesel supply in the world. In European countries especially Austria, Spain, France and Italy, market share of diesel-based cars has exceeded 50% since 2006 [12]. Based on the current consumption of about 11.6 million tons of crude oil per day, it is expected that the entire resources can only suffice for a rather short time period [18; 22]. Analysing global oil depletion, the UK Energy Research Centre has stated that a peak of conventional oil production will be reached between 2020 and 2030 when well-available resources will be used [21]. However, new oil and gas reserves have constantly been found. The most exciting discovery is according to the new geological surveys that as much as a fifth of the world's undiscovered, but exploitable gas and oil reserves lie under the Arctic ice [9]. In this situation, potential oil and gas refining will increase fossil-fuel reserves, thus causing the risks of the exponential rise of greenhouse effect, which can result in all kinds of catastrophes to our planet Earth and its inhabitants. One of the evidently exiting problems is that the high number of on-road diesel vehicles implies that emissions from the engines contribute significantly to the atmospheric levels of the most important greenhouse gas, $CO_2$ and other urban pollutants such as CO, $NO_x$, unburned hydrocarbons, particulate matters and aromatics [7].

To confront the global climate changes, renewable and alternative energy needs to be developed and applied in practical situations. Biodiesel produced from algae is one of the options to relieve the urgent demand pressure mentioned above. Algae, a potential energy feedstock, have a much higher oil yield than any other feedstock currently being researched. It has been calculated that in order to replace petro-diesel completely by extracting oil from a crop such as soybean or palm, a very large percentage of the current land available needs to be utilized only for biodiesel crop production, which is quite infeasible [13]. For some small countries, in fact it implies that all the land available in a country should be dedicated to biodiesel crop production. In addition, algae, which does not require additional fertilizers or pesticides like many farmed crops do, can be easy to be cultivated in grey water or waste water, even on marginal land. Therefore it does not occupy land used in farming for food. Moreover, it simply requires $CO_2$ and sunlight to grow. The carbon release through biodiesel combustion is initially fixed from $CO_2$ gas through photosynthesis. Thus, microalgae biodiesel is carbon neutral. Undoubtedly, microalgae are a superior alternative as a feedstock for large-scale biodiesel production.

There are several stages for environmentally friendly extraction of biodiesel from algae such as: growing or cultivating, harvesting, drying, oil extraction and transesterification, leftover reuse and possible wastewater treatment. Each stage is an organic and indispensable component of the whole microalgae-based biodiesel supply chain. The main focus on biodiesel production from algae is how to manage each process smoothly in order to make microalgae-based biodiesel production competitive and cost-effective. In other words, the overall purpose of the microalgae-based biodiesel supply chain for energy use is basically twofold: (1) production costs can be minimized to keep the product competitive [5]; (2) continuous feedstock supply can be guaranteed to make the production system optimized and smooth [20].

## 1.1 Existing approaches

The current or existing method known for microalgae biodiesel production is basically the normal growing of microalgae being it grown in ponds, in huge laboratory tubes, etc. After growing, they are manually harvested for pre-treatment or sent straight away to the production plant for microalgae biodiesel production. This environmentally friendly renewable, carbon free, transport fuels are therefore, essential for environmental and economic sustainability of the production. Algae have emerged as one of the most promising renewable-energy sources for biodiesel production. This seems rather incidental that microalgae harvested in CO2-enriched air can be converted to oily substances for the production of microalgae bio-diesel. This approach contributes to solve major problems of air pollution resulting from CO2 evolution and future crisis due to a shortage of energy sources, which could be renewable and also environmentally friendly production systems. Biodiesel is one of the most significant components to mitigate green-house gas emissions and substitute of fossil fuels [4].

Energy consumption both in the domestic and commercial scale is currently on very high demand due to the increase in industrialization and population. The basic sources of energy in use on both commercial and domestic scale currently, are petroleum, natural gas, coal, hydro and nuclear plants [8]. The use of petroleum-based fuels is a major disadvantage to atmospheric pollution coursed by using fossil diesel. Therefore, the use of petroleum diesel in combustion is a major effect on the environment same as that caused by greenhouse gas (GHG). According to [19] microalgae biodiesel production is one of the best sources of biodiesel. In fact, the microalgae diesel produced are of the highest quality thus, yielding feedstock for biodiesel production. This method of green-diesel production can produce up to 250 times the amount of oil per acre as soybeans. Therefore, producing biodiesel from microalgae may be the only way to produce enough automotive fuel to replace current gasoline usage in an environmentally friendly approach.

According to [6] algae produce 7 to 31 times greater oil than palm oil. It is very simple to extract oil from algae. The best algae for biodiesel would be microalgae. Microalgae are organism capable of photosynthesis that is less than 2 mm in diameter. Macro algae, like seaweed, are not widely in use as in the production of biodiesel. Microalgae contain much more oil than macro algae, and it is much faster and easier to grow and harvest [19].

## 2 SUPPLY CHAIN MANAGEMENT EFFICIENCY

Incorporating the principles of supply-chain management into the production of microalgae, enabled by information technology (IT) driven efficient systems for this process, and it represents an option to enhance the efficiency of algae-based supply-chain management production. Supply-chain management is a business strategy to improve operational and customer value by optimizing the flow of products, services and related information from source to customer. Processes of creating and fulfilling the market's demand for goods and services in a supply chain as well as a trading partner community engaged in a common goal of satisfying the end customer. Therefore, it is an organization of the overall business processes to enable the profitable transformation of raw materials or products into finished products and their timely distribution to meet customer demand.

The initial stage of the microalgae production in the supply chain is the biomass generation. This can be via natural generation or cultivation, which applies to microalgae. The second stage is harvesting, from manual harvesting, still also used for seaweeds in Ireland, is by way of using continuous automated flow for some microalgae. The third step is pre-treating the generated or harvested biomass, including cleaning, desalination, dewatering and drying (when needed). A further stage is grouped under Downstream Processing that can vary depending on the energy generation route selected. Finally, the market or end customer aspects from a bio fuel end-user perspective are considered. Table 1 below presents an overview of the supply chain for both resources and the aspects which need to be considered, while Figure 1 below illustrates the stages of the optimization flow model within the supply-chain management microalgae biodiesel production process.

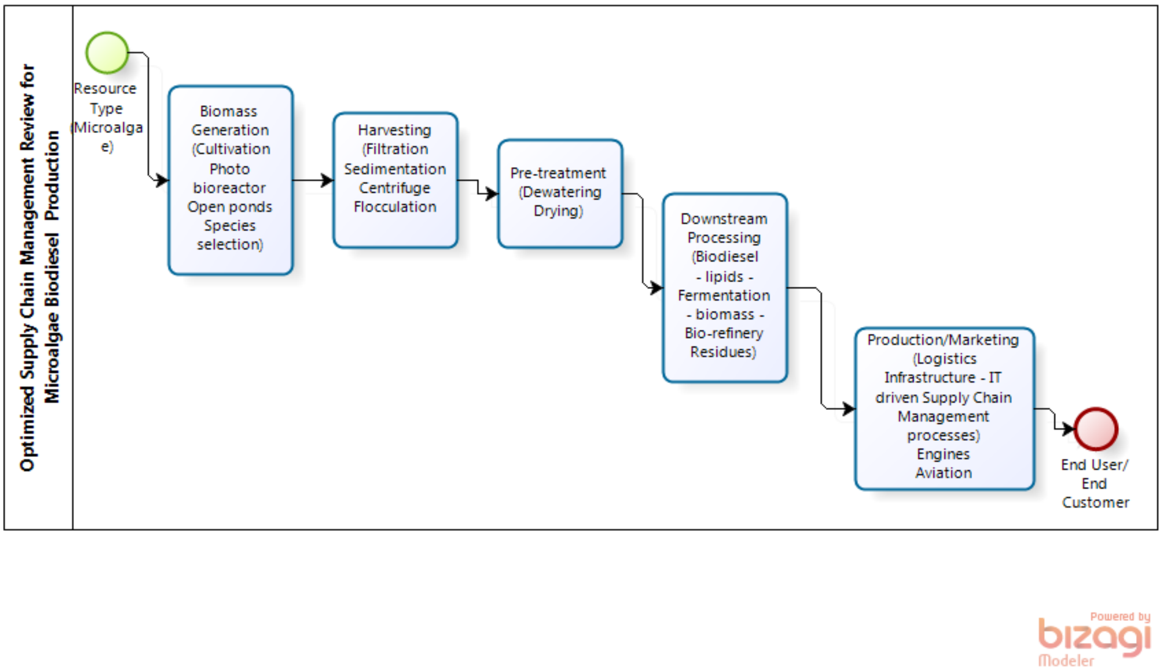


***Fig. 1:*** *Optimized Supply-chain management in Management Review for Microalgae Biodiesel Production.*

***Tab. 1:*** *Optimized SCM in Management Review for Microalgae Production.*

| Resource Type | Biomass Generation | Harvesting | Pre-treatment | Downstream Processing | Marketing |
|---|---|---|---|---|---|
| Microalgae (Phytoplankton) | Cultivation Photo-bio-reactor Open ponds Species selection | Filtration Sedimentation Centrifuge Flocculation | Dewatering Drying | Biodiesel (lipids) Fermentation (biomass) Bio-refinery Residues | Logistics Infrastructure - (IT driven Supply Chain Management processes) Engines Aviation |

Source: [1]

Using IT driven supply-chain management in management principles in microalgae based biodiesel production would enhance its rapid production competitiveness in four key directions: responsiveness, reliability, resilience and relationships/networking. In today's world of just-in-time products or services, the ability to respond to customers' requirements in an ever-shortened lead-time has become very critical. Nowadays, not only do customers want a shortened lead-time but also flexibility and highly customized products or services. Therefore, suppliers are required to meet the exact demands of customers in lesser time than ever before. Thus, one of the optimum reasons why any company stores safety stock is because of uncertainty. This could be due to suppliers' inability to meet demand, the quality of production/services or uncertainty in future product/service demand. The marketplace today is characterized by higher levels of turbulence and volatility. Pursuant to this, a resilient IT driven, supply-chain management system will be required to cope with the unexpected turbulence and volatility. This case a single source of supply network is widespread, and this comes along with suggested benefits, including innovation sharing, improved quality, reduces cost and integrated scheduling of production and deliveries [3].

This paper investigates the integration of the benefits of IT driven supply-chain management for efficiency of the environmentally friendly algae-based biodiesel production. Based on this investigation a framework for the integration will be suggested. It includes research questions, and initial findings directed to outline the future solutions and applications. The ultimatum aim of the paper is the advancement of environmentally friendly productions supported by IT systems for the well-being of our global society.

### 2.1 Supply chain issues and methods

Until now, microalgae-based biodiesel production exists in two types: small-scale and large-scale activities. In this paper, we only explore the supply-chain issues of the large-scale production, since the relative issues during the small-scale production are not evident and the process is simple to follow. As there are several processes before biodiesel production, especially for large-scale extraction, including harvesting/collecting, transport, storage, and pre-treatment. The main operations along the supply chain need to ensure constant, stable, and competitively-priced feedstock supply for energy conversion plants. These operations are coordinated and optimized by the design of the overall supply system as illustrated in Figure 2 below.

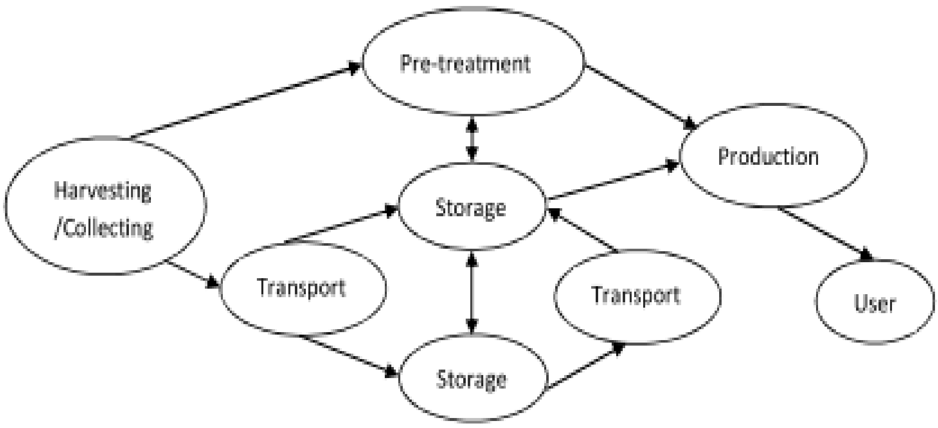


***Fig. 2:*** *Feedstock supply system of microalgae-based biodiesel production.*

In order to optimize the efficiency of the whole processes, there are some sub-questions that need to be dealt with as follows:

### 2.3 Harvesting/Collecting

Main methods for harvesting include centrifugation, filtration, and flocculation [23; 17]. Cost-effective and energy-efficient harvesting methods are required to make the whole biodiesel production process economical. However, most importantly, the period and frequency can influence latter process. Too many harvestings will be the burden for transport, especially for storage.

### 2.4 Transport

The place of harvesting/collecting and the sites of extraction are usually not identical, transport is required. The main economic factor of transport is the time spent on the travel [16], which is dependent on two variables: (1) distance [14] and (2) speed [10].

### 2.5 Storage

The location of warehouse for biomass inventory needs to be thoroughly chosen as the biomass might come from different places, and the warehouse might also supply the storage for many extraction plants. Another impact is that the warehouse will undertake the risk that biomass may go decayed because of expired storage. Both the location of warehouse and storage time will influence the storage cost [2].

### 2.6 Pre-treatment

Drying is considered to be the most energy-intensive part of this process [15]. There are many ways to dry the wet biomass that comes out of the centrifuge. Which level of drying is sensible for three aims: to save on energy costs for this process, to avoid biomass decay and can meet the requirement for the next process.

### 2.7 Extraction

There are three factors, which will influence the efficiency of oil production. Firstly, the plant location should benefit from storage and transport; secondly, size and capacity are dependent on quantities of the biomass and the supply speed; lastly, different extraction methods have variable relative efficiencies.

If all the procedures can be coordinated effectively, the production can be optimized and the market price of biodiesel can be competitive. On the basis of factors mentioned above, a simulation game can be designed to make the whole processes optimized as much as possible.

## 3 A FRAMEWORK FOR LOGISTICS AND SUPPLY CHAIN USING THE SIMULATION GAME.

### 3.1 The simulation game

The simulation game is a logistics and supply chain management production optimization approach that have the objective to optimize the logistics and entire supply-chain management of the production process from the upstream (the farmers' harvesting fields) through the intermediate-stream (the storage, pre-treatment and production processes) to the downstream where the microalgae biodiesel is finally supplied or distributed to the end customers. The optimization in these processes happens by endeavouring to introduce or make the production process leaner. Therefore, the simulation seeks to enquire into ways where storage time could be significantly reduced in the storage of harvested algae to prevent decayed waste. Because the harvest tends to decay when stored longer than necessary, which means that they have to be disposed-off as they will be no good for quality microalgae diesel production. Furthermore, the simulation game also reveals some of the slags in the transportations' times as well as manpower utilization efficiency.

The simulation game is performed by defining one person to be responsible for each of the microalgae biodiesel production processes depicted in Figure 2 above, from the upstream through the intermediate-stream to the downstream.

Thus, one player is responsible for each of the following processes:

- Harvesting / Collection
- Transport / Logistics
- Storage
- Pre-treatment
- Production
- User

For an effective simulation analysis, it is suggested that the game will always start with the assumption that the harvest / collection is already completed. Thus, the time and production optimization process from the simulation game starts from transport / logistics through to the end user. A couple of assumptions are considered in this simulation game:

Working hours per a day = 8 hours
Therefore, 1 working day = 8 hours
Hence, 24 hours = 1 day = 8 hours
Therefore working hours per a day in seconds = 8/24 = 0.3 seconds
Therefore 1 working day = **0.3 seconds** (as assumed in the proposed simulation game)

### 3.2 The objectives and purpose of the simulation game

***Tab. 2:*** *Simulation Game Concept Analysis*

| Processes | Objectives | Purpose | Remarks |
|---|---|---|---|
| Harvest/ Collection | This is the stage where the grown algae are collected and screened. | To harvest healthy algae for microalgae biodiesel production purposes | This should be done properly and within laid done principles in order to obtain the required maximum harvest possible. |
| Transport/ Logistics | At this stage the collected microalgae form the harvest is transported to the storage awaiting immediate or pre-treatment within the shortest possible time to avoid the decay of the harvest. | To keep it under the required temperature and environmental conditions till the harvest is sent through to the pre-treatment stage to avoid decay of the | Optimized logistic arrangement is very essential at this stage within the required temperature conditions to still keep the microalgae still fresh for pre-treatment and subsequent biodiesel |

| | | | |
|---|---|---|---|
| | | harvest. | production. |
| Storage | Good temperature and environmental storage conditions is essential and optimum at this stage in the supply chain | To minimize the storage time as much as possible to avoid decay due to over storage. | Minimizing storage time will go a long way to contribute to lean microalgae biodiesel production as well as optimize the supply chain by making it more efficient and effective. |
| Pre-treatment | This is the stage in the supply chain where all the impurities, bits of algae decays and excess water is removed from the collection, making it finer and ready to be sent through to the production stage for microalgae biodiesel production. | To enhance a lean and more efficient and effective supply chain by achieving a finer harvest free from impurities, decay and excess liquid. | Promoting an optimized supply chain and lean production |
| Production | This is the stage in the supply chain where the pre-treated microalgae are sent through the production machinery lab for microalgae biodiesel production. | Lean microalgae biodiesel production. | Optimized supply chain. |
| End User | Clear, clean and environmentally friendly microalgae biodiesel is produced and ready for both domestic and industrial utilization | Environmentally friendly microalgae biodiesel produced to enhance and promote green and renewable energy production. | Customer satisfaction is achieved taking into account the corporate social responsibility of energy production. Clean and environmentally friendly microalgae biodiesel production. Optimized supply chain and much leaner microalgae biodiesel production. |

### 3.3 Concept

As there are some processes before biodiesel production, especially for large-scale extraction, including harvesting/collecting, transport, storage, pre-treatment. So the whole system needs to be optimized. The purpose is to make the feedstock supply stable in order to assure that the production process can be preceded smoothly.

There are some sub-questions that we can deal with as follows:

- ✓when to harvest(period and frequency)
- ✓storage: cost, risk (avoid possible decay), location
- ✓transport: distance, speed, social and environmental impacts
- ✓pre-treatment: naturally drying or heat drying, and its efficiency.
- ✓extraction: plant size and scale, production methods.

If all the procedures can be coordinated effectively, the production can be optimized and the price can be competitive. A simulation game can be designed to make the whole process optimized as much as possible.

Figure. 3 below illustrate the proposed optimization simulation board game which is to optimize the logistics and supply chain as well as make the production leaner. The simulation game below in Figure 3 assumes the followings:

$T_{H/C}$ = Harvest / Collection time (1)

$T_{T/L}$ = Transport / Logistics time (2)

$T_S$ = Storage time (3)

$T_{Pt}$ = Pre-treatment time (4)

$T_{Pr}$ = Production time (5)

$C_{H/C}$ = Capacity of Algae Harvested / Collected per day (6)

$C_S$ = Capacity of Algae Stored in the Storage per day (7)

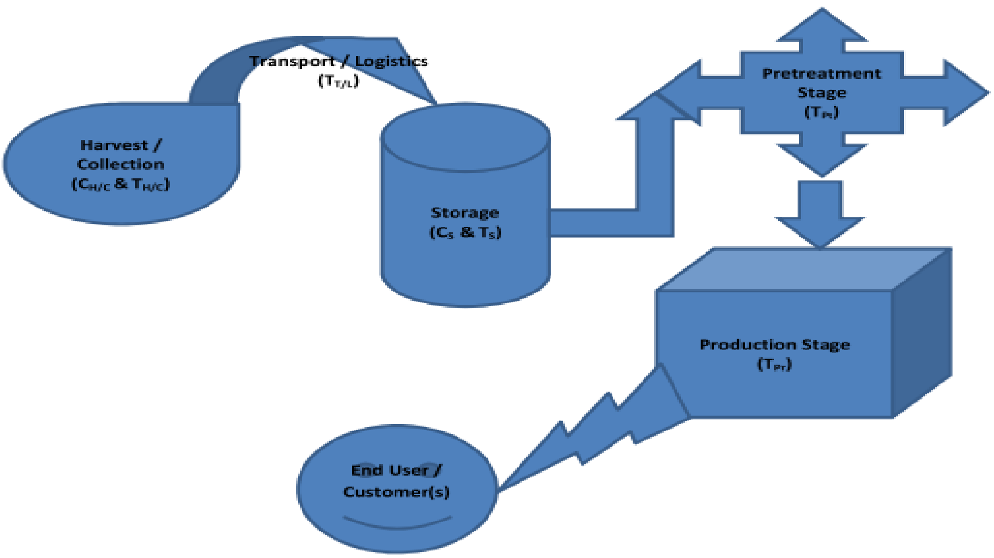


***Fig. 3:*** *Feedstock supply system proposed simulation board Game for optimizing microalgae-based biodiesel production.*

### 3.4 Findings

In this paper supply-chain management is apparently defined as a production network management system that supplies microalgae environmentally friendly biodiesel production from the raw harvest of the algae at the upstream level to the final customer at the downstream level of the supply chain. This whole management network system is embedded with the commercially common objective of efficiency and effectiveness in the production making the whole process leaner. Efficiency is a cost oriented competitive advantage while effectiveness is a competitive advantage of customer specification reactions within the supply-chain management network. Thus, efficiency is achieved through just-in-time (JIT) microalgae biodiesel production as well as the transport / logistics system while effectiveness is achieved through customer specifications in terms of quality and delivery times [11]. Therefore, at any stage of the simulation of the supply chain, using IT systems as proposed or assumed in the process will make the supply chain more efficient. Thus, ideally the simulation if performed in real time will optimize the production in real time. This idea is the essence behind the proposed application of simulation game above in Figure 3.

## 6 CONCLUSION AND RECOMMENDATIONS

The preceding sections above have undoubtedly revealed that incorporating the principles of supply chain management enabled by information technology (IT) driven systems, enables more efficient and effective systems for the processes involved with algae-based biodiesel production. This vehemently supports the notion proposed that supply-chain management and effective supply chain management enhance with IT systems is when the exchange value of activity systems fulfils the expectations that make up the customer specification or use value. Therefore, further research into effective and efficient successful integration of IT systems into the production chain of microalgae-based biodiesel is highly recommended for effectiveness and efficiency in the production chain.

This paper has demonstrated that microalgae-based biodiesel is a clean-burning alternative and renewable fuel, whose production is environmentally friendly. There are many strengths to produce microalgae as a biodiesel feedstock, for instance, high photosynthesis efficiency, high oil content and noncompetition with traditional agriculture on farmlands. Large-scale microalgae-based biodiesel processes involve with harvest/collection, transport, storage, and pre-treatment. In order to optimize the efficiency of the whole processes, this paper applies and presents a simulation game of the biomass supply-chain management and logistics for energy production. The approach of the simulation game proposes a rough pattern for analysis and highlighting primary features in biodiesel production efficient supply chain. The smooth and coordinated operations along the supply chain can ensure constant, stable, and competitively-priced feedstock supply for energy conversion plants that creates the basis for implementing leanness.

Undeniably, microalgae-based biodiesel is produced in an environmentally friendly manner. However, in order to develop and commercialize a sustainable product in the long term, the operations must be coordinated and optimized to support a sustainable supply chain. There are some recommendations during microalgae-based biodiesel production. For example, the life cycle analysis at the biodiesel product design phase and the biomass usage planning must be conducted to foresee the potential risks during the whole process. International regulations, guideline standards for sustainable microalgae production must be brought in and adopted. Collaboration between partners has to be encouraged so that the investment capitals can be collected more easily and the advantages of technologies can come into effect. The transparency of process inputs and outputs must be exercised. Finally, public perception and participation of microalgae industry as an environmentally responsible steward will help facilitate its establishment and development. Only in this way, algal biodiesel industry as well as the linkage to supply-chain management gain advantage and deliver prosperity in an environmental friendly manner.

At several stages of the micro-algae based bio-diesel production supply chain IT support systems can be used. The requirements for these systems are outlined in this paper within the proposed framework. Future work will include an analysis of the detailed specifications of these systems that will contribute to efficient supply chains of micro-algae environmentally friendly production of bio-diesel.

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