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SUPPLY CHAIN OF JATROPHA CURCAS BIODIESEL INDUSTRY BASED ON LOCAL PRODUCTION AND CONSUMPTION IN CUBA

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Abstract

The Cuban efforts for the founding of a local biodiesel industry are totally focused on Jatropha based, as the main source of bioenergy for transportation in rural areas. There is no a national policy in this respect and the producers and users are dealing with the use of a blend of 15% of biodiesel of Jatropha curcas and 85% diesel fuel. This is a major challenge for the farmers and municipalities, due to risk and uncertainty in its production, profitability and land disposal, among others. The present study investigates the supply chain network and related problems of the biodiesel industry in Cuba. The Jatropha based biodiesel supply chain includes stages like seeds production, feedstock logistics such as harvesting, storage, and transportation, biodiesel production, distribution and final use in diesel engines. The critical factor is the seed production at the level needed for a stable supply of oil to the biodiesel plant. Consumables that are imported are another risk factor in the Jatropha value chain in Cuban local production.

The settling of a local bioenergy market is another task for the Jatropha industry but also for the by-products generated (glycerol, Jatropha cake and husk) are also crucial for the sustainability of the industry.

Keywords: Jatropha curcas, supply chain, SCOR, biodiesel**.**

Introduction

The consumption of fossil fuels, the derived exhaust emissions and their estimated reserves are spotlight issues in the world. In this scenario, several green energy alternatives have been under research, development or being implemented in the economy and society. In this respect, biodiesel (BD) production from different feedstocks is a strong established market. Nevertheless, biodiesel technology has been a target concerning its competition with food production. Even when this is a subject where the society, scientific community, policy makers and stakeholders are not always agreed, certainly biodiesel technology has been migrated to one generation to other until the fourth. In this line, biodiesel production at local scale and for energy supply to cover local needs is a concept more related to sustainability, and even is a strong support to food production and local employment [1,2]. Cuba is focused on this approach and the selected the *Jatropha curcas* plant is the main seed for oil extraction and biodiesel production in the island. Since this is a system designed and developed to production and consumption at local scale in farmer areas, it simplifies the supply chain and the logistic involved in biodiesel production from well to wheel. Nevertheless, the Cuban agroindustrial system, economy and the special conditions of the country generate critical issues that tackle the main target, which is biodiesel production from Jatropha seed.

The scope of this contribution is to describe the actual supply chain and related problems of the *Jatropha curcas* biodiesel industry in Cuba, its challenges, operational conditions, but the development of a methodology based on the SCOR model for further application to the studied system.

Productive chain of biodiesel production in Cuba

The agroindustrial production of biodiesel of *Jatropha curcas* in the Cuban context obeys the general scheme shown in Figure 1, but with particularities, and the main ones are the local harvesting of Jatropha fruits, biodiesel production and use. The scheme is separated by three sectors, where the service sector is quite simplified due to its aim is to solve energy problems in rural areas nearby the biodiesel plant. The flowsheet concerning the industrial part follows the traditional basic catalyzed transesterification, with a previous mechanical oil extraction, avoiding the use of chemicals. The main stages included in the Biofuels Supply Chain (BSC) are: feedstock production, biodiesel production, blending, distribution and use.

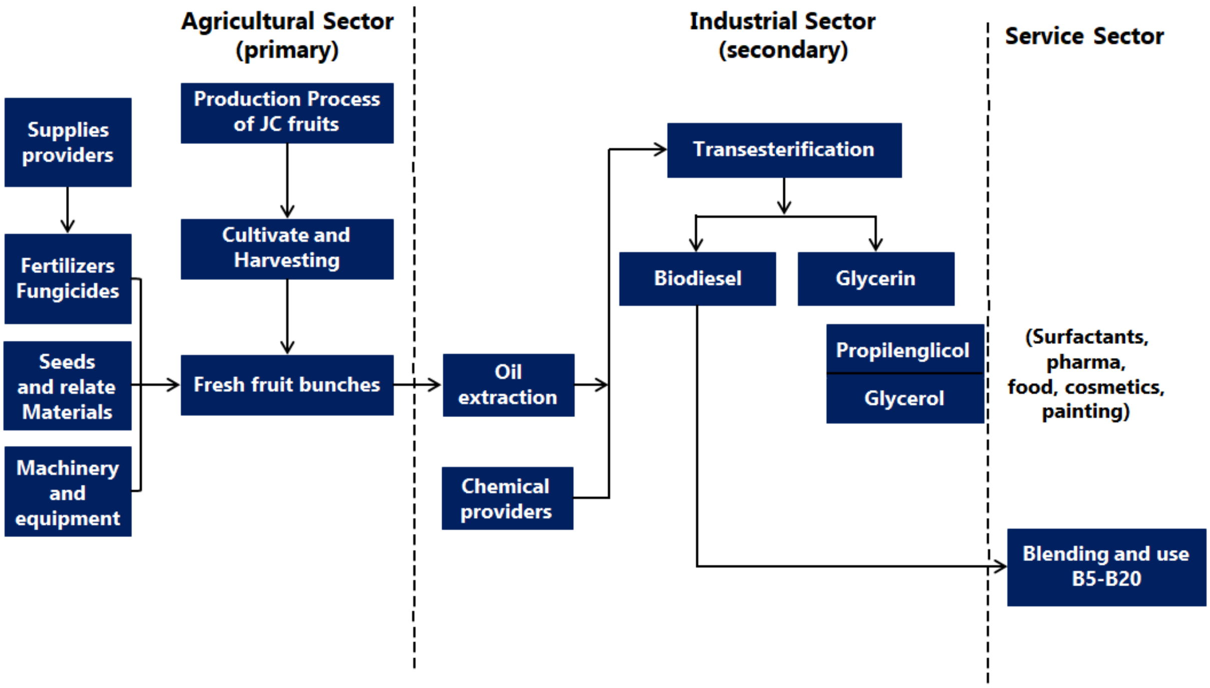

Fig.1 Productive chain of *Jatropha curcas* biodiesel production in Cuba

The flow structure based on agricultural biomass for biodiesel production is shown in Figure 2, which represent a version based on [3]. It is a multilevel network that includes: potential and location of farms (F), storage sites (S), pre-processing facility (P), biodiesel production facility (BDP), distribution (D), fuel service (G) and clients or final users (C). The elements in Figure 2 indicated in colour (green) are those taken in to account in the Cuban system, based on the basic scheme proposed. Models applied to the productive chain of biodiesel production have shown that they are more related with the upstream processes. This is because it is the main feed of the entire chain but also because represents the most variable factor, because the oil source is totally different for different scenarios, countries, etc. (Palm, rapeseed, soybean, Jatropha, straight vegetable oils or fatty acid distillates). The midstream processes are well optimized since biodiesel production is an established technology, and is in this case study also, where the biodiesel plant was fully purchased in the market.

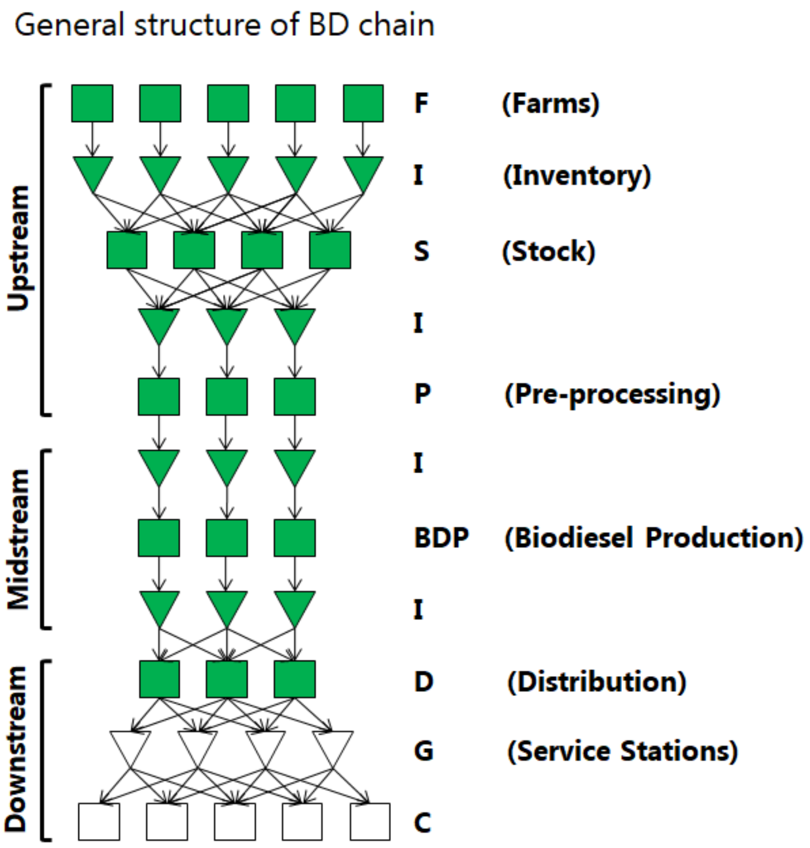

Fig.2 General and particular structure of the productive biodiesel supply chain

The supply chain is defined by the following elements: farmers, oil extracting and conversion unit, suppliers and users. A typical biodiesel supply chain has as separated elements the extraction unit and the conversion unit. In this case, there is the advantage of being an integrated system. Another feature of a typical supply chain is the distribution of fuel produced to wholesalers, which is a key for bringing the final product B5-B20 (biodiesel blended with diesel fuel from 5% to 20%) to the users or clients. In this case, these chain elements are integrated and simplified. This is due the analyzed scenario is adapted to the real one established in Guantánamo province.

Estimation of biodiesel demand

In the modeled case study, biofuel demand estimation is based just in a local scenario of mobility of the local enterprise which manages the biodiesel plant, and the biofuel demand is bases on their own and not local town or other society actors. In this respect the next assumptions of standardized automotive consumers are taken into account: diesel cars as average the same performance of a Toyota Hilux 7.1 L/100 Km, trucks (type KamAZ) 25 L/100 Km, tractors (John Deer) 16 L/h under regular field performance. It is important to point out this is a standard assumption foe modeling but does not correspond to the real vehicle stock at the agroindustrial system. Additionally, part of the modeling is to take into account the covered distances in any activity but especially the two-ways to the Jatropha plantations settled at variable distances of the conversion plant, between 5 and 20 Km. Calculations of fuel consumptions are related to input data under the real operational conditions of transports, always using B20 as the maximum blend.

Criteria for the selection of hectare for Jatropha curcas cultivation

The actual work is based on a case study related to an already existing system. Therefore, the previous design and adequate search of places for Jatropha cultivation are already done. The criteria taken into account are based in four macro criteria: climate conditions, sustainability, social and logistics.

In the second group the main factor is land availability (mainly arid land) for Jatropha cultivation. The fourth group includes the percentage of land able for seeding, infrastructure and distance to the fruits processing facility. Barely 90 hectare of *Jatropha curcas* are settled in the area under study (Farm Paraguay in Guantánamo, Cuba). As average criteria, the plantations are in an area not larger than 20 Km from the treatment facility, but the real distances must be taken into account in the modeling.

Methodology based on the SCOR model to analyze the supply chain of Jatropha curcas biodiesel production

The Supply Chain Operations Reference model (SCOR) provides lines for the processes enhancement and practices related to the supply chain. The procedure for its application is based on analysis of competence basis, supply chain configuration, levels of performance, practices and systems. The SCOR levels are: plan, source, make, deliver and return.

In this study, the field information is based on a biodiesel facility settled in Guantánamo province, Cuba. This way, valuable information is retrieved for processes analysis in the actual supply chain model and those activities which generate improvements. With the collected information, the supply chain of BD production of *Jatropha curcas* is characterized by the SCOR application. In this respect for the methodology design, the biodiesel productive environment includes seed harvesting capacity, distribution and transport, oil processing and conversion, by-products handling and commercialization.

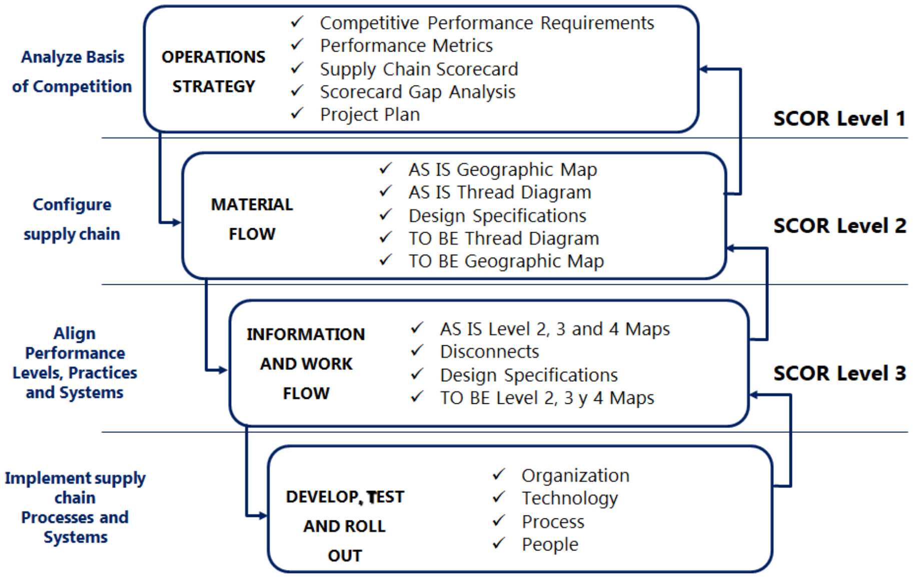

Fig.3 Project plan based on SCOR

The model is based on the management of indexes which have five main attributes of performance [4]:

Reliability: (reliability on delivery): perfect order fulfillment, percentage of orders delivered on time, product conditions and quality. But in this case study is a minor attribute due to the biodiesel delivery is in the own company and in rural areas surrounding the facility, but its quality is still a main issue. Nevertheless, the system is modeled as a more general scenario.

Agility: seeking for an advantage concerning the delivery of other biofuels or increases in the biofuel demand, also related to climatic changes influencing biodiesel production.

The maximum sustainable percentage increase in quality delivered that can be achieved in 30 days, and the maximum feedstock increase to be acquired is in 30 days.

Responsiveness: change of the supply change to supply products by a changing demand; order fulfillment cycle time, source cycle time, making processes cycle time and delivery cycle time.

Cost: all cost inside the supply chain as vegetable oil and chemicals.

Assets: effectiveness in the management of assets to reach a demand emphasizing on processes enhancement.

To apply the model, different levels in which it is structured are taken into account (see Figure 3). The processes of the supply chain for biodiesel production from *Jatropha curcas* are defined as:

Source: Cultivation of *Jatropha curcas*, from seeding to harvesting.

Make: logistic operations related to the obtaining of the vegetable oil and biodiesel production. It also takes into account the operations with the industrial by-products.

Deliver: storage, delivery, transportation and distribution.

Return: this is valid for Source and Make where back operations could take place.

A fifth element, Plan, is presented in all the supply chain, from cultivation planning and control until the delivery to the final user.

The indexes of logistic performance are shown in Table 1. The SCOR card for biodiesel production from *Jatropha curcas* is shown in Table 2.

Table 1. First level indexes. Adapted from [4]

	Market			Internal	
Attributes	**Reliability**	**Responsiveness**	**Agility**	**Cost**	**Asset**
Delivery performance	X				
Fill rate	X				
Perfect order fulfillment	X				
Order fulfillment lead time		X			

Response time of the chain			X		
Production flexibility			X		
Administrative cost				X	
Sell cost				X	
Guaranty cost and returns				X	
Time of payments cycle					X
Inventory offer					X
Assets change					X

The information presented in Table 2 corresponds to a hypothetic scenario of biodiesel production near to the real one targeted. For designing and modeling purposes it is useful because let us to develop the modeling and in several cases the indicated values are corresponding with the reality of the biodiesel production in Cuba. Nevertheless, the scenario is based on biodiesel production at a local scale. Some indexes present values far from logic behavior found in literature, but correlated to those particular and special conditions of the Cuban economy and society.

Table 2. SCOR card for biodiesel production from *Jatropha curcas*

Attribute or category	Metrics Level 1	Actual	Goal	Gap	Comments
Reliability	Perfect order fulfillment	70%	95%	25%	Gaps related to the upstream processes mainly
	Percent of orders delivered in full	80%	100%	20%	
	Delivery performance to customer commit date	60%	90%	30%	
	Documentation accuracy	90%	100%	10%	
	Perfect condition	80%	95%	15%	
Responsiveness	Average time for supplies purchase (days)	90	90	0	
	Average time per 400 L batch BD (days)	3	2	-1	Optimization of operational processes
	Average	72	48	-24	

	delivery time (h)				
Agility	Days to increase BD production in 20%	7	3	-4	Variable
	Max increase of chain	0%	5%	5%	
	Days to increase stocks by 20%	90	90	0%	
	Days to increase delivery by 20%	7	3	-4	
	Max increase in production	25%	25%	0%	
Cost	Cost of keeping the supply chain	100%	90%	-10%	10%
	Planning cost	80%	50%	-30%	
	Production cost	10%	10%	0%	
	Cost of transport and delivery	10%	8%	-2%	
Assets	Cycle of cash flow (days)	30	25	-5	Higher cash flow
	Cycle of cash flow for providers (days)	30	30	0	

The application of the SCOR model to the biodiesel production from *Jatropha curcas* offers advantages and is a model that represents a formal methodology clearly applicable to the Jatropha supply chain. Nevertheless, there are no enough reports about the application of SCOR to the supply chain of biodiesel of any feedstock based on local economy.

Normally, in biodiesel agroindustry systems, several processes are treated as isolated and not fully integrated. The systemic approach regularly fails, and in this particular case study which is not the exception in this respect, the critical part is the agroindustrial sector until fruits delivery at the treatment and extraction facility. Beside this, the purchase and receiving of consumables, mainly chemical reactants for the chemical conversion are also a limiting factor, due to they must be imported, impacting in the whole supply chain model.

According to Table 2, the analyzed system shows several opportunities based on the gaps found. The supply chain of biodiesel production from *Jatropha curcas* in Cuba has a very critical element, which is the Jatropha fruits production, affecting all the chain. Secondly is the acquisition of assets which also affect the effectiveness and efficiency.

Further Research

The system under study is based on the use of between B5 to B20 which is demonstrated that under more complex technological and supply conditions, is possible to reach minimal costs [5]. Further research on biodiesel supply chain should be focused on location of plantations, production, blending, transportation, and flow amount in each stage [6]. The modeling should be focused (after redesign and fully establishment of an effective supply chain) on optimize economic cost; minimize environmental impact by calculating Green House Gases emissions in each stage of the chain and for every transportation used. Future research can also minimize conflict with food security, but in this respect by the using of semi-arid land and by applying inter cultivations between Jatropha and food plants this issue is already attempted.

Conclusions

A general description of a *Jatropha curcas* biodiesel production focused in application of SCOR to the supply chain was proposed. This approach opens a window for future researches in this specific field and subject and especially for the Cuban context is a starting point for a deep assessment of biodiesel production from Jatropha, that the country pretends to introduce in at least three provinces. The integration of these systems must be also part of further modeling. The critical part of the supply chain is the production of fresh fruits, which is today affecting biodiesel production under a system that is quite simplified compared to other biodiesel agroindustrial supply chains.

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