A note on the potential of CNSL in fuel blends for engines in Brazil

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Abstract
CNSL is a by-product of the cashew industry which is the pericarp fluid of the nut. Main producers (India, Nigeria and Brazil) cannot store CNSL as a commodity. The international consumers market is unstable. Thus there is a potential for the use of CNSL in fuel blends in Brazil. Fuel mixtures with 1, 2, 5 and 10% of CNSL may provide savings of in 0.82, 1.63, 4.08 and 8.16%, respectively. However, the blends imply in considerable changes in fuel viscosity and require an investigation on the impacts on engine performance and on part components. A more detailed survey on economical viability should also be addressed due to price variations of CNSL and fuels for the mixtures.
Keywords: CNSL. Fuel blends. Biofuel.

Resumo
O LCC é um subproduto da indústria de caju, que é o fluido do pericarpo da noz. Os principais produtores (Índia, Nigéria e Brasil) não podem armazenar o LCC como uma *commodity*. O mercado de consumidor é instável, sugerindo um potencial para o uso do LCC em misturas de combustível no Brasil. Misturas com 1, 2, 5 e 10% de LCC podem prover poupanças de 0,82; 1,63; 4,08 e 8,16%, respectivamente. Porém, as misturas de combustível indicam mudanças consideráveis na viscosidade dos combustíveis e requerem uma investigação do impacto no desempenho de motores e componentes. Uma pesquisa mais detalhada sobre a viabilidade econômica deve ser endereçada com base nas variações de preço do LCC e dos combustíveis para formulação das misturas.
Palavras-chave: LCC. Misturas de combustíveis. Biocombustível.

1 Introduction

Energy is essential to economic and social development. It is intrinsically linked to the improvement of the quality of life. However, much of the world's energy is currently produced and consumed in ways that will not sustain if technology remains constant and if overall quantities be ever increasing. At the same time, the necessity to control emissions of greenhouse and other gases must be based on the efficiency in energy production, transmission, distribution and consumption. In a simplified context a description of the energy systems can be according to the figure below.

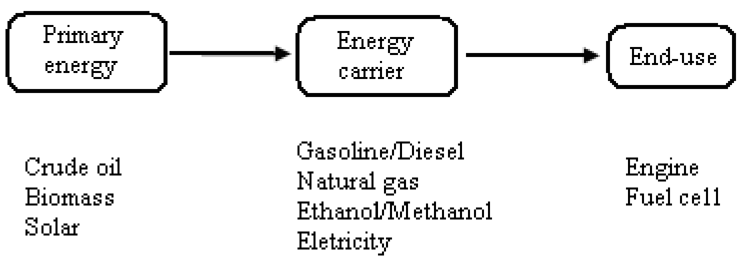

Figure 1: Energy systems

The continuous growing in demand for energy and environmental awareness has brought research to produce alternative fuels from renewable resources and environmentally more acceptable. High petroleum and gasoline prices, concerns over global climate change, and the desire to promote domestic rural economies have supported the interest in biofuels as an alternative. The use of alternative fuels as source of energy, mainly in the sector of transports, will not only contribute to the environmental quality but also has several inserts in the socioeconomic field, as shown in the Table 1. In parallel, it is important to remind that the technical potential for biofuel realization will vary depending on a number of geopolitical and economical drivers shown in Table 2 (SLINGERLAND and VAN GEUNS, 2005).

Table 1: Main advantages of the production of biofuels.

Advantage	*Comment*
Environmental	Velocity increase for reaching goals proposed by the Protocol of Kyoto, through MCD (Mechanism of Clean Development), with potential qualification of projects in the CCM (Carbon Credit Market). Reduction of emissions of sulfur, up take of CO_2 by vegetable biomass (carbon sink) with minimization of the greenhouse effect, improvement of the air quality, general waste reduction and pollution.
Regional development	Potential for the generation of job opportunities and family income, decrease in population migrations, smaller effects of protectionism in the agricultural sector. Greater dynamics in the capitalist logic, with recover or elevation of consumption patterns, greater dynamism in technology transfer, review of the productive system, with a more competitive productive chain.
Diversification of energy matrix	Smaller dependence on fossil fuels, development and incorporation of new technologies for the use of fuels, invigoration of the transport logistics.
Financial	Real profit in several sectors of the economy, through the reduction of consumption of fossil fuels.
Economic exchange value	Reduction of expenses with imports of petroleum.

Source: adapted from IEA (2004).

Table 2: Geopolitical and economic drivers for biolfuel production.

Geopolitical drivers	*Economic drivers*
Supply, security and risk abatement Post Kyoto reduction emission agreement Interaction with new parties and policies Multilateral international certification	Petroleum prices Biomass prices Technological development

Source: Slingerland and van Geuns (2005).

Besides the complexity in establishing effective policies for the production of biofuels most of the researches are focused on the improvement of the conversion technologies. Also, they explore technical and economical aspects of use of the biomass as a renewable source of energy. There is, therefore, a well established technical and scientific knowledge. Table 3 presents a synthesis on the potential biofuels, with respective biomass sources and productive process, except for that obtained by anaerobic digestion (i.e. biogas).

Table 3: Biofuels, potential biomass sources and processes.

Biofuel	*Source*	*Process*
Ethanol Methanol Buthanol	Sugar cane, corn, sorghum, eucalyptus, beet, cellulose	Hidrolysis + fermentation
Biodiesel	Castor oil plant, soy been, cotton seed, peanut, sunflower and canola	Extraction + (trans)esterification

Source: adapted from Ma and Hanna (1999); Yacobucci and Schnep (2007).

By the end of the last century Bartholomew (1981) suggested that fossil fuels would become an alternative to biofuels. At that time there were already fuel mixtures for engines. For instance, in Brazil heavy machines engines, diesel types, worked well with pre-combustion chambers. The engines operated with mixtures of 10 and 20% of vegetable oil, without potency loss, alterations of technical concept or need of adjustments. It was also from this period the enforcement of the Brazilian project for the use of the ethanol as biofuel and in gasoline blends. However, most studies on fuel blends are still for diesel engines (e.g. SILVA, SANTOS and BARBOSA, 1998; SEBOS *et al*., 2008).

2 CNSL – source, composition and use

Cashewnut Shell Liquid (CNSL) is a soft honey comb structure containing a dark reddish brown viscose liquid. It is a by-product of the cashew industry which is the pericarp fluid of the nut. Main producers are India, Nigeria and Brazil (RODRIGUES *et al*., 2006). It is considered to be better as well as cheaper material for unsaturated phenols and imported by industrialized countries. Raw cashewnut shell contains around 20% oil (WASSERMAN and DAWSON, 1948; EDOGA, FADIPE and EDOGA, 2006). Main commercial processes for the extraction of CNSL are mechanical or by solvent use. In Brazil the most applied technique consists in the immersion of the cashewnut in a hot bath of CNSL at 185-190°C (RODRIGUES et al., 2006). The method recovers about 50% of CNSL and this hot extraction produces a different CNSL from the natural, obtained by cold extraction. Due to the heat the anacardic acid undergoes descarboxilation and it is converted to cardanol. This oil is called technical CNSL. A comparison between natural and technical CNSL is in Table 4, and basic chemical composition shown in Figure 2.

Table 4: Composition of CNSL.

Phenolic compounds	***Composition of CNSL (%)***	
	Natural	*Technical*
Anacardic acid	71.0 – 82.0	1.1 – 1.8
Cardanol	1.2 – 9.2	60.0 – 68.0
Cardol	3.8 – 20.1	15.0 – 18.1
2-methylcardol	1.6 – 3.9	1.0 – 3.3
Others	0 – 2.0	0 -7.4

Source: adapted from Gedam and Sampathkumaran (1986); Kumar et al. (2002).

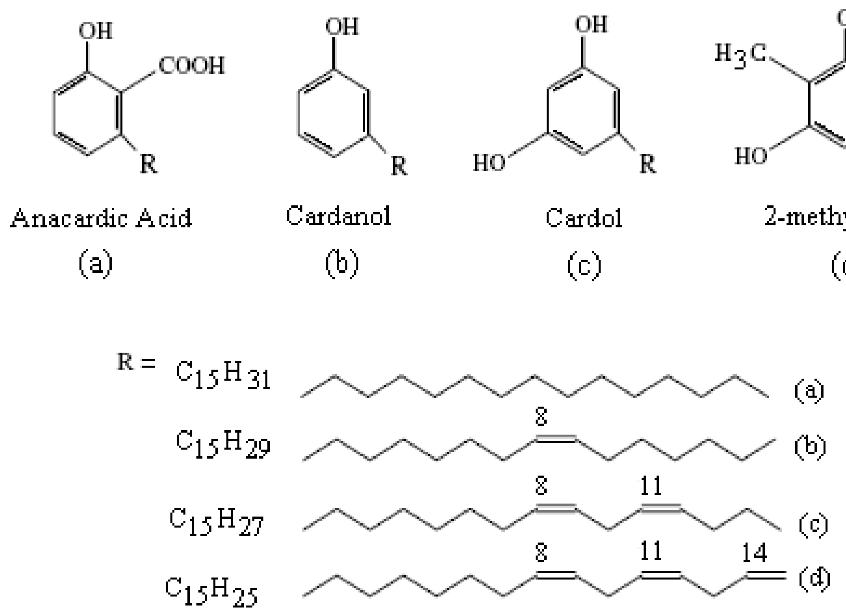

Figure 2: Structures of constituents of CNSL.
Source: Toschi *et al*. (1993).

CNSL is a versatile product and is used for brake linings of motor vehicles, paints, varnishes, and laminated products, as plywood adhesive, and as a low-cost replacement for phenol in novolak and resole resins. After phosphorylation, as a component to increase the tensile properties and flame retardation of natural rubber; and as a long-life, highly bioactive, antifouling coating for marine environments using paints with varying proportions of CNSL-modified rosins. CNSL or extracts from the shell of the cashew nut have larvicidal, molluscicidal, antifungal and antibacterial activity (MENON *et al*., 1985; SANTOS and MAGALHÃES, 1999; PARAMSHIVAPPA *et al*., 2001; CARDOLITE, 2002; CARIOCA *et al*., 2008).

In spite of its potentialities, in general CNSL does not aggregate value to the productive chain of the cashew producer. Most of the CNSL is solely exported in the form of industrial by-product. Consumption of CNSL by cashew producers is low and the degree of processed liquid for the production of more attractive industrial products is also small.

In a recent study Matos, da Silva and Vieira (2008) found that technical CNSL produced in Brazil may reach US$ 300/ton in favorable sceneries. In the form of hydrogenated cardanol and phenolic resins the mean values may be US$ 1,500 and US$ 500/ton, respectively. These authors sustain that the consumption of CNSL in the international market is unstable, based on the fact that CNSL has a coefficient of variation about 40% in the consumption by the international market and 25% in price. Also, apparently there is no correlation between price and exportation by producers.

3 CNSL for fuel blends

Tuli *et al*. (2004) and Kumar *et al*. (2006) highlight that CNSL can be used as an antioxidant and added to fuels and lubricants. The production of these blends will benefit directly the agribusiness of the cashew (CARNEIRO *et al*. 2005; SILVA *et al*., 2005). Additives are chemical products with specific functions, produced by the chemistry industry, with high aggregated value. Thus, its use improves lubricant and fuel properties, and provides new characteristics to the organic substrata.

In petroleum derived products additives are used in small amounts to limit deterioration or to stabilize properties, mainly color and viscosity, what guarantees their stability. The use of CNSL as bioadditive in engines increases the durability of pieces and equipments. The antioxidant activity is derived from cardanol and comparable to synthetic commercial products (LOPES *et al*., 2008).

Therefore, the use of the liquid of the cashew nut brings advantages, because, it is a raw material renewable, biodegradable and abundant. The production of CNSL as bioadditive will replace imports, besides preserving the environment with lower pollutant residues. It should be highlighted that cashew tree is resistant to droughts, and possesses social and economical character, accrediting the culture as a species capable to generate wealth. The liquid of the cashew nut is a mixture that varies in the insaturation degree linked to the group of n-benzene nucleus.

For Brazilian producers CNSL can be use in fuel blends, been attractive because of potential economy in overall fuel consumption. Table 5 shows the characteristics of CNSL as a fuel, and others commonly used in engines in the Brazilian transportation sector. The mixture of fuels with the technical CNSL at proportions of 1, 2, 5 and 10% would produce the blends shown in Table 6.

Table 5: Characteristics of CNSL as fuel and others used in engines.

Characteristic	***Fuel***				
	CNSL[a]	Diesel	Ethanol	Gasoline	Gasoline + 22% ethanol (BRG)
Viscosity cps	395	3.35	1.19	0.40	0.58
Density	0.965	0.820	0.800	0.750	0.76
Heat capacity kcal/kg (MJ/kg)	9,400 (39.3)	10,200 (42.7)	6,400 (26.8)	11,100 (42.8)	10,066 (39.3)

Source: [a] CIONE (2008) and NYLUND et al. 2005.

Table 6: Characteristics of blends of common fuels with technical CNSL.

Blend	***Mixture (% of CNSL)***	***Viscosity cps***	***Density***	***Heat capacity***	
				kcal/kg	*MJ/kg*
Gasoline + CNSL	1	4.35	0.752	11,083	42.8
	2	8.29	0.754	11,066	42.7
	5	20.13	0.761	11,015	42.6
	10	355.54	0.944	9,570	39.7
Diesel + CNSL	1	7.27	0.821	10,192	42.6
	2	11.18	0.823	10,184	42.6
	5	22.93	0.827	10,160	42.5
	10	42.52	0.835	10,120	42.3
Ethanol + CNSL	1	5.13	0.802	6,430	26.9
	2	9.07	0.803	6,460	27.0
	5	20.88	0.808	6,550	27.4
	10	40.57	0.817	6,700	28.0
BRG + CNSL	1	4.52	0.763	10,059	39.3
	2	8.46	0.765	10,053	39.3
	5	20.30	0.771	10,033	39.3
	10	40.02	0.781	9,999	39.3

Changes in the original characteristics compared to the new blends indicate more critical information, especially because of considerable variations in viscosity (shown in Table 7). Therefore, a detailed investigation should be addressed to the effect of these fuel blends on engine performance and components.

Table 7: Variation (%) of viscosity, density and heat capacity of the fuels blends with CNSL.

Blend	*Mixture (% of CNSL)*	*Viscosity cps*	*Density*	*Heat capacity*	
				kcal/kg	*MJ/kg*
Gasoline + CNSL	1	987	0.29	-0.15	-0.08
	2	1,973	0.57	-0.31	-0.16
	5	4,933	1.43	-0.77	-0.41
	10	88,785	25.80	-13.78	-7.30
Diesel + CNSL	1	67	0.18	-0.08	8.41
	2	157	0.35	-0.16	8.32
	5	427	0.88	-0.39	8.07
	10	877	1.77	-0.78	7.64
Ethanol + CNSL	1	331	0.21	0.47	0.47
	2	662	0.41	0.94	0.94
	5	1,655	1.03	2.34	2.34
	10	3,309	2.06	4.69	4.69
BRG + CNSL	1	687	0.27	-0.07	0.00
	2	1,375	0.54	-0.13	0.00
	5	3,437	1.34	-0.33	0.01
	10	6,874	2.68	-0.66	0.01

In Brazil, according to PROCON (2008), the commercial price of vehicle fuels during the last year were 1.30, 1.12 and 0.89 US$/litre, for gasoline (BRG), diesel and ethanol, respectively. These values were based on an exchange ratio of R$ 1.89/US$. The average value of CNSL was US$0.1965/litre according to Matos, da Silva and Vieira (2008). While the coefficient of variation of the fuels prices was 11% for CNSL it was 25%.

A simulation on money saving with fuel blends was computed for gasoline, diesel and ethanol vehicles working with equivalence to 10,000 km/year (Table 8). The performances were estimated as 8.0, 3.0 and 5.6 km/l, respectively. The prices were calculated by simple balance according to the mixtures. Obviously, the highest savings can be obtained with higher degrees of mixtures.

Table 8: Percentage of money saving by using fuels blends with CNSL.

Mixture %	*Fuel and saving (%)*		
	BRG	**Diesel**	**Ethanol**
1	0.85	0.82	0.78
2	1.69	1.65	1.56
5	4.23	4.12	3.89
10	8.46	8.24	7.79

In spite of the apparent economy in fuel consumption it is reasonable to consider a variation in the prices of the blends. Thus, a simple Monte Carlo simulation was conducted with 1,000 runs in a uniform distribution and a coefficient of variation of 11% in fuel prices. It provided a more critical figure with regard to the risk of expending more money than by using the commercial fuels. Results were only encouraging for gasoline blends. As expected the lowest risks were for the fuel blends with high degrees of mixture (Figure 3).

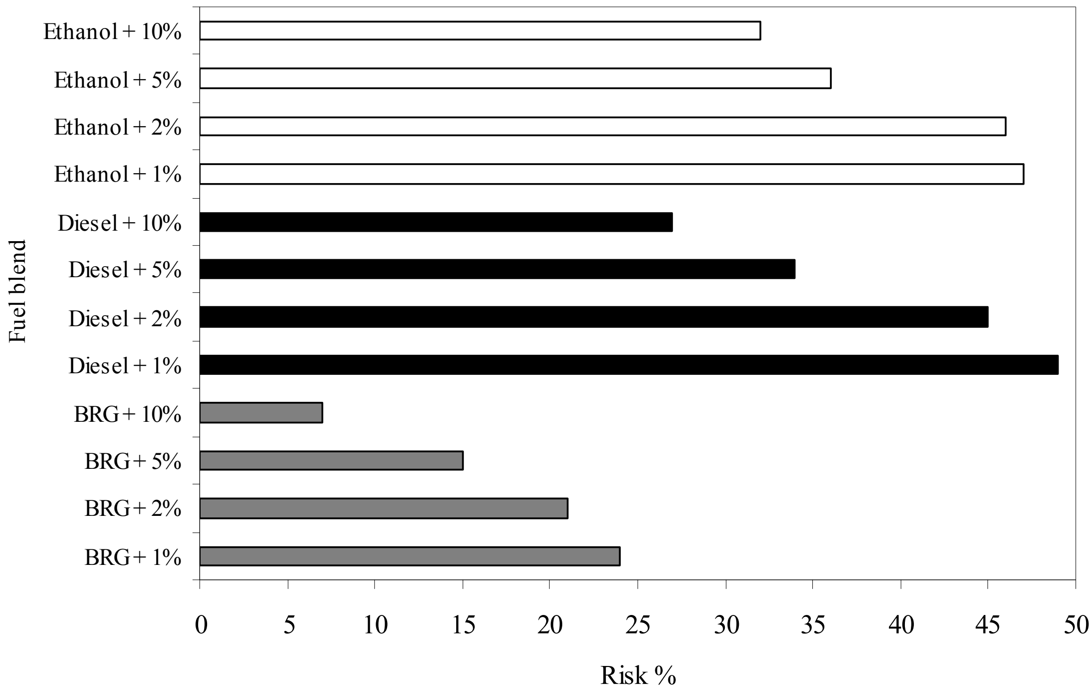

Figure 3: Risk of failure in saving with different blends of fuels with CNSL, taking into account a coefficient of variation of 11% in the prices.

4 Final remarks

The industries cannot store CNSL as a commodity. Therefore, there is a potential for the use of CNSL in fuel blends in Brazil. However, it is necessary to conduct research on the effect of fuel mixtures on engine performance and impact on components. This is particularly important with regard to the increase in viscosity. Also, it is necessary to remove impurities at least by filtration mainly due to polymerization.

A more detailed investigation on economical and financial viability should also be addressed since price variations of CNSL and fuels may turn the use a non viable approach.

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