Cabinet of the Minister

General Coordination of Support to Sectorial & Thematic Chambers – CGAC

Sectorial Chamber for the Oilseeds & Biodiesel Production Chain

Uses for BIODIESEL in Brazil and Globally

1st Edition

Ministry of Agriculture, Livestock and Food Supply

Ministry of Agriculture, Livestock and Food Supply
Cabinet of the Minister
General Coordination of Support to Sectorial & Thematic Chambers – CGAC
Sectorial Chamber for the Oilseeds & Biodiesel Production Chain

Uses for BIODIESEL in Brazil and Globally

1st Edition

Brasília - Mapa
2015

Ministry of Agriculture, Livestock and Food Supply
Cabinet of the Minister
General Coordination of Support to Sectorial & Thematic Chambers – CGAC
Sectorial Chamber for the Oilseeds & Biodiesel Production Chain

Esplanada dos Ministérios, Bloco D
Brasília, DF
CEP: 70.043-900

Minister of Agriculture, Livestock & Supplies
Kátia Regina de Abreu

President of the Sectorial Chamber for the Oilseeds & Biodiesel Production Chain
Odacir Klein/ Pedro Ferreira Granja Jr.

Technical Development
Leonardo Botelho Zilio – Coordinator (ABIOVE – Brazilian Association of Vegetable Oil Industries)
José Honório Accarini –Rapporteur (Civil House of the Presidency)
Antonio Carlos Ventilii Marques (APROBIO – Brazilian Biodiesel Producers Association)
Daniel Furlan Amaral (ABIOVE – Brazilian Association of Vegetable Oil Industries)
Donato Aranda (UBRABIO – Brazilian Biodiesel and Biojetfuel Union)
Donizete Tokarski (UBRABIO – Brazilian Biodiesel and Biojetfuel Union)
Eduardo Soriano Lousada (MCTI – Ministry of Science, Technology and Innovation)
Fillipe Augusto da Costa Garcia (ANP – National Agency of Petroleum, Natural Gas and Biofuels)
Gabriela Menezes (MAPA – Ministry of Agriculture, Livestock and Food Supply)
Gustavo de Lima Ramos (MCTI – Ministry of Science, Technology and Innovation)
Isabel Regina Carneiro (MAPA – Ministry of Agriculture, Livestock and Food Supply)
João da Silva Abreu Neto (MAPA – Ministry of Agriculture, Livestock and Food Supply)
João Norberto Noschang Neto (Petrobras Biocombustíveis – Petrobras Biofuel)
Julio Cesar Minelli (APROBIO – Brazilian Biodiesel Producers Association)
Mário Augusto de Campos Cardoso (CNI – National Confederation of Industry – Brazil)
Rafael Silva Menezes (MCTI – Ministry of Science, Technology and Innovation)
Sergio Tadeu Cabral Beltrão (UBRABIO – Brazilian Biodiesel and Biojetfuel Union)
Tiago Quintela Giuliani (MAPA – Ministry of Agriculture, Livestock and Food Supply)

Uses for Biodiesel in Brazil and Globally – 1st Edition
Report presented to the Sectorial Chamber for the Oilseeds & Biodiesel Production Chain in June 2015.
Brasilia, 2015.
Image Credits: Cover: Alexandr Dubovitskiy/Thinkstock. Inner pages: Mapa/Thinkstock; Sílvio Ávila/Mapa; ABIOVE; Grupo André Maggi.

Catalogação na Fonte
Biblioteca Nacional de Agricultura – BINAGRI

Brasil. Ministério da Agricultura, Pecuária e Abastecimento.
Uses for biodiesel in Brazil and Globally / Ministério da Agricultura, Pecuária e Abastecimento. Gabinete da Ministra.
– Brasília : Mapa/ACE, 2015.
38 p.

ISBN 978-85-7991-097-5

1. Combustível. 2. Biodiesel. 3. Agricultura. I. Gabinete da ministra. II. Série.

AGRIS P06
CDU 662.7

Contents

List of Acronyms

ANP	National Petroleum, Natural Gas & Biofuels Agency
BX	Terminology used to designate the percentage of biodiesel blended into diesel A
CARB	California Air Resources Board
CEN	European Committee for Standardization
CFPP	Cold Filter Plugging Point
CONAMA	National Environmental Council
CSHVC	City Suburban Heavy Vehicle Cycle
DCN	Derived Cetane Number
DENATRAN	National Traffic Department
EPA	Environmental Protection Agency of the United States
FAME	Fatty Acid Methyl Esters
FETRANSPOR	Federation of Passenger Transport Companies in Rio de Janeiro State
TF	Task Force
PROCONVE	Program to Control Atmospheric Pollution by Motor Vehicles
S-10/S-500	Designation of sulphur content in mineral diesel
URBS	Curitiba's Urbanization & Sanitation Company

Executive Summary

This report summarizes the results of the Task Force (TF), formed in the 21st ordinary meeting of the Sectorial Chamber for the Oilseeds & Biodiesel Production Chain, held on November 11, 2014, for the purpose of identifying and consolidating information on the results of the tests and experiments using different blends of biodiesel and mineral diesel in Brazil and globally.

The TF was formed with representatives from government entities (Civil House of the Presidency, MAPA, MCTI, Petrobras Biofuels and ANP) and private entities (ABIOVE, APROBIO, CNI and UBRABIO). After presenting an overview of the Brazilian fleet equipped with diesel cycle engines, around four million vehicles in 2014, of which about 60% were classified in PROCONVE's Phases P5 and P7, this report addresses the specifications of the biodiesel adopted in Brazil, showing that they are compatible with those in effect globally, especially in the United States and in Europe, and that some parameters, especially those related to water content, are more rigorous.

Supported by an analysis matrix, 57 studies on the subject were summarized, covering the impacts of blends equal or superior to 10% biodiesel in fossil diesel – called high blends – on important basic items, such as: fuel consumption, emissions, cold starts, the engine's power and performance, and the durability and wear of components.

Generally speaking, the benefits and disadvantages of using high blends of biodiesel were within expectations (all quantified), although some studies on the subject had different results for average behavior, such as reduction in fuel consumption and nitrogen oxides (NOx) emissions. As regards cold starts, the engine's power and performance, and the durability and wear of components, the results generally show that using high blends does not bring significant impacts in these items.

In Final Considerations, this report concludes that adopting procedures and taking care to maintain the biodiesel's specifications, and with technical advances providing more adequate materials for use in contact with the biodiesel, progressively tend to avoid problems when using biodiesel, regardless of the specific diesel-biodiesel blend used.

Introduction

Provisional Measure No. 647/2014, converted into Law No. 13033/2014, raised the percentage of the compulsory blend of biodiesel in diesel B to 7%. This level has been in effect throughout Brazil since November 1, 2014. Notwithstanding Brazil's robust compulsory and duly regulated market, which should produce and consume over four billion liters of biodiesel in 2015, there is legal provision for using other blend percentages. In this way, within specific and controlled circumstances, it would be possible to use different percentages of biodiesel in diesel B, such as 20% (B20), 30% (B30), 50% (B50) or even 100% (B100). This reality can also be found globally as various countries are testing and using different biodiesel percentages.

The purpose of this report was to collect and systematize information on the uses of biodiesel in Brazil and globally, specifically those with high BX (henceforth defined as "high blends"), i.e., those equal or superior to 10%. Diverse databases were consulted – such as publishers of journals reviewed by peers, private and government institutions with an international reach – in search of tests, experiments and scientific articles related to the use of high blends of biodiesel over the last few decades.

This Task Force carefully sought solid data and information from reliable sources, whose representativity was believed to be applicable to the current domestic reality. However, documents from the 1980s or 1990s were not discarded. Even though automotive technology and fuel quality from that time tend to diverge, at times significantly, from current standards, incorporating this information was thought to enrich this report by bringing an important historic characterization and evolution for a better understanding of the current challenges and opportunities.

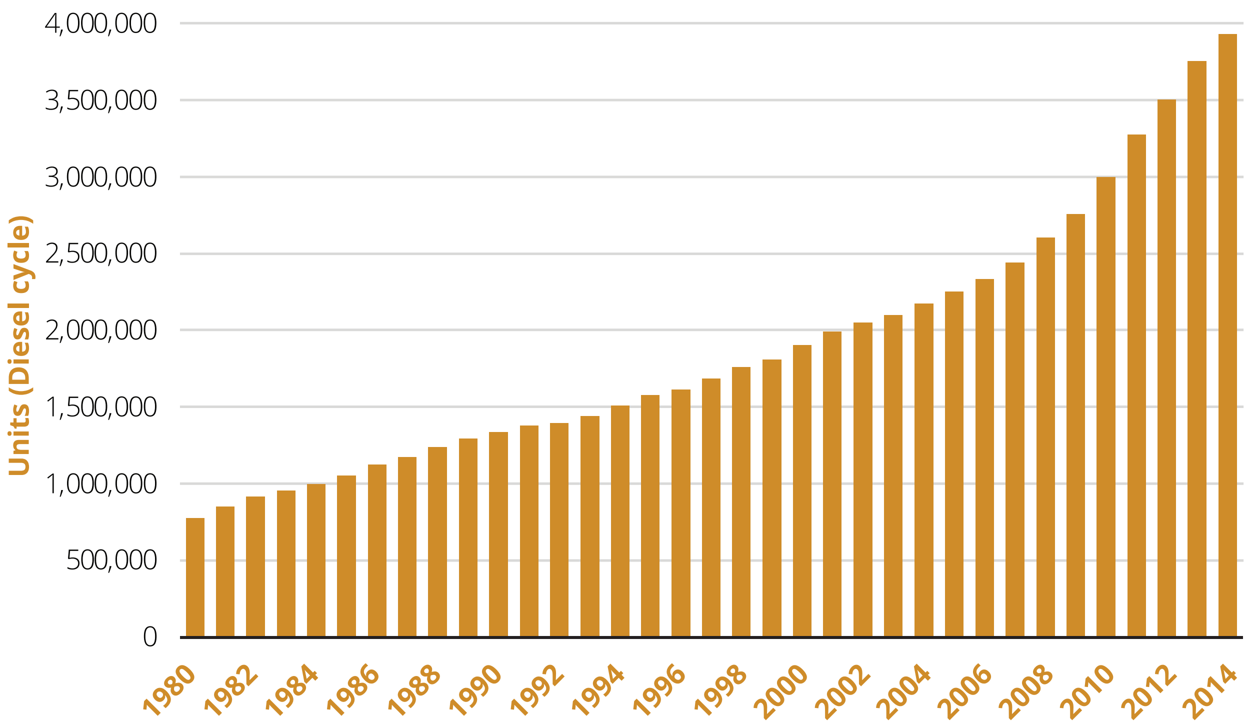
Nonetheless, the use of high blends of biodiesel was observed to be a common practice among many fleet managers, even though the results of such tests are rarely published.

Finally, it is hoped that the contents here presented may contribute to the discussions on the use of biodiesel as a motor fuel, as well as serve to support researchers, users and decision-makers.

Brazilian Fleet: Diesel Cycle

According to MMA (2014), about 3.5 million diesel cycle vehicles circulated in Brazil in 2012. Furthermore, according to DENATRAN's data, approximately 700,000 new vehicles in this category were licensed in Brazil between 2013 and 2014. Taking into account the scrapped fleet, four million diesel cycle vehicles are currently estimated to be in circulation, with over half that number beginning their useful life after the year 2000.

Figure 1: Estimated fleet evolution of diesel cycle vehicles in Brazil



Fonte: MMA (2014) and DENATRAN

MMA (2014) further addresses the distribution of the fleet in accordance with PROCONVE's phases1. In 2012, the last year with available data, 50% of the domestic diesel fleet belonged to PROCONVE's Phases P5 and P7, 21% to Phase P4, 9% to Phase P3, 10% to Phase P2 and 10% to Phase P1 or P0. Given the evolution of scrap and the new licenses, it is estimated that, in 2014, about 60% of the fleet is now classified in the Program's Phase P5 and P7.

1 In Brazil, PROCONVE created emission limits in 1986, defining the limits for emissions by diesel vehicles. Currently, emission limits are defined as a function of the vehicle's cargo capacity. Heavy vehicles comply with CONAMA's Resolution No. 403/08. The regulated emissions are carbon monoxide (CO), non-methane hydrocarbons (NMHC), nitrogen oxides (NOx) and particulate matter (PM).

Specifications for Diesel and Biodiesel in Brazil and Globally

When comparing the specifications for the biodiesel currently produced in Brazil, in the U.S., in the European Union and in Canada, there are only minor differences.

Brazilian specifications (ANP Resolution No. 45/2014) are the most rigorous as regards water content. The 200 mg/kg limit adopted in Brazil is about half that allowed in the rest of the world, but it is a necessary requirement due, for example, to the logistic peculiarities of an extensive domestic territory. It should be noted that biodiesel's high hygroscopicity demanded investments in Brazilian factories, not only to bring the biodiesel to below this level, but also to maintain it at that level during transportation and storage. Currently there are discrete tolerance criteria for the biodiesel producer and the fuel distributor in inspection activities.

Canada is considerably more demanding as regards residues of alkaline metals, earth alkaline metals and phosphorus.

The European Union has some specific analyses, such as "linolenic ester content" and "polyunsaturated esters content". These analyses are more restrictive regarding raw material than the process, as they are related to the biodiesel's oxidative stability – a parameter included in domestic biodiesel specifications at the same value as the European standard. It should be highlighted that Brazil does not use raw material with high concentrations of linolenic acids or in proportions that could generate compatibility problems with the European market.

There are also some distinct specifications regarding the properties related to cold, such as CFPP, the pour point and the dew point. These parameters are related to each country's winter specifications. In the U.S. and Canadian markets, the cold pour point parameters are shown as 'annotate', as their dynamics are based on agreements between the producer and the buyer, taking into consideration the proposed application, the addition of additives in the distribution or the use of installations that have devices to maintain the biodiesel's temperature above that of the environment and in good condition.

A comparison between Brazilian specifications and U.S. specifications shows a Brazilian requirement significantly greater as regards oxidative stability and water content, with great similarity among the remaining parameters. This shows the high quality adopted by biodiesel specifications in Brazil.

Table 1: Specifications of biodiesel in Brazil and globally

		Brazil	United States	European Union	Canada
Normative Instruction		ANP Resolution No. 45/2014	ASTM D6751-15	EN14214:2012	CAN/CGSB-3524-2011
Designation		B100	Grade 1-B e 2-Bd	FAME	B100
Year of implementation		2014	2015	2014	2011g
Parameters	**Unit**				
Aspect	-	LIIa	-	-	-
Specific density at 15ºC, min - max.	kg/m³	850–900 (20ºC)	-	860 – 900	Annotate
Kinematic viscosity at 40ºC, min – max.	mm²/s	3.0 – 6.0	1.9 – 6.0	3.5 – 5.0	1.9 – 6.0
Water and sediments, max	%vol	-	0.05	-	-
Water content, máx.	mg/kg	200b	-	500	400
Total contamination, max.	mg/kg	24	-	24	-
Flash point	ºC	100	93	101	130
Distillation temperature, 90% recovered, max	ºC	-	360	-	-
Ester content	%mass	96.5	-	96.5	-
Linolenic ester content	%mass	-	-	12.0	-
Polyunsaturated esters content	%mass	-	-	1.0	-
Carbon residue, max	%mass	-	0.05	-	0.05
Sulphated ashes, max	%mass	0.02	0.02	0.02	-
Total sulphur, max	mg/kg	10	15 / 500	10	Annotate
Sodium + potassium content, max	mg/kg	5	5	5.0	4
Calcium + magnesium content, max	mg/kg	5	5	5.0	2
Phosphorus content, max	mg/kg	10	10	4.0	4
Corrosivity to copper, 3h at 50ºC	Degree	1	3	1	-
Cetane number	-	Annotate	47	51	Annotate
Cold filter plugging point, max	ºC	c	-	f	-
Dew point	ºC	-	Annotate	-	Annotate
Cold filterability	s	-	d	-	
Acid value, max	mg KOH/g	0.5	0.5	0.5	0.5
Free glycerin, max	%mass	0.02	0.02	0.02	0.02
Total glycerin, max	%mass	0.25	0.24	0.25	0.24
Monoglycerides, max	%mass	0.7	0,4/ -d	0.7	-
Diglycerides, max	%mass	0.2	-	0.2	-
Triglycerides, max	%mass	0.2	-	0.2	-
Methanol/ethanol, max	%mass	0.2	0.2e	0.2	0.20
Iodine index, max	g of I2/100g	Annotate	-	120	-
Stability to oxidation at 110ºC, min	Hours	8	3	8	8

Ta. B100 can only be considered non-compliant after evaluation of water content and total contamination.
b. For the purpose of inspections, the following values are adopted: 250 and 350 mg/kg for the producer and distributor, respectively.
c. Because of large regional variations, differentiated limits are adopted by state throughout the year (Table II of RANP 45/2014).
d. ASTM D6571 establishes that Grade 1B should present cold filterability (ASTM D7501) of 200 and has a maximum monoglycerides content (ASTM D6584) of 0.4%. Grade 2B should present 360 for the cold filterability test and there is no maximum limit for monoglycerides.
e. If the sample presents a flash point above 130ºC, there is no need to test methanol/ethanol content.
f. Bearing in mind that FAME is used in a wide range of temperatures within the European Union, CEN established six specifications for cold fluidity (Grade A – F) with cold filter plugging point values varying from +5 to -20, respectively. For use in Arctic climates, Classes 0 – 4 were additionally defined with values varying from -20 to -44ºC, respectively.
g. The standard that establishes the specifications for B100 in Canada (CGSB CAN/CGSB-3.524) was revised in 2014. However, ANP does not have access to this version of the standard so the data here reported refers to the 2011 version.

Table 2: Specifications of diesel in Brazil and globally

		Brazil	United States	European Union	Canada
Normative Instruction		ANP Resolution nº 50/2013	ASTM D975-15	EN590:2013	CAN/CGSB-3.520-2011
Designation		S10/ S500	1-D / 2-D	Temperado / Ártico	Tipo A/ Tipo B
Year of implementation/revision		2014	2015	2014	2011
Parameters	**Unit**				
Aspect	-	LII	-	-	-
Color	-	a / Red	-	-	-
ASTM color, max	-	3.0	-	-	-
Biodiesel content	% vol	7.0	5.0	7.0	1.0 – 5.0
Distillation					
10% vol, recovered, max	ºC	180.0 / Annotate	-	-	-
50% vol, recovered, max	ºC	245.0 – 295.0 / 245.0 – 310.0	-	-	-
85% vol, recovered, max	ºC	360.0 (S500)	-	350	-
90% vol, recovered, max	ºC	Annotate (S500)	288 / 282 – 338i	-	290 / 360
95% vol, recovered, max	ºC	370.0 (S10)	-	360	-
Specific density at 15ºC, min – max	kg/m3	815.0 – 850.0 / 815.0 – 865.0 (20ºC)	-	820.0 – 845.0/ 800.0 – 840.0	-
Kinematic viscosity at 40ºC, min – max	mm2/s	2.0 – 4.5 / 2.0 – 5.0	1.3 -2.4 / 1.9 – 4.1i	2.0 – 4.5 / 1.2 – 4.0	1.3 – 3.6 / 1.7 – 4.1
Water and sediments, max	% vol	0.05 (S500)b	0.05	-	0.02
Water content, max	mg/kg	200 / 500c	-	200	-
Total contamination, max	mg/kg	24 (S10)b	-	-	-
Flash point	ºC	38.0	38 / 52i	55.0	40
Ramsbottom carbon residue in 10% final distillation, max	% mass	0.25	0.15 / 0.35	0.30	0.1 / 0.2
Ashes, max	% mass	0.01	0.01	0.01	0.01
Total sulphur, max	mg/kg	10d / 500	15	10	15
Total aromatics, max	% mass	-	35h	-	-
Polyaromatics, max	% mass	-	-	8.0	-
Corrosivity to copper, 3h at 50ºC	degree	1	-	-	-
Cetane number or derived cetane number (DCN), min	-	48 / 42	40h	51.0 / 47.0 – 49.0	40
Cetane index, min	-	-	-	46.0 / 43.0 – 46.0	-
Cold filter plugging point, max	ºC	e	-	5 to -20/ -20 to -44j	-
Dew point, max	ºC	-	i	-10 to -34ºC (Arctic)	Annotate
Acidity value, max	mg KOH/g	Annotate	-	-	-
Lubricity, max	µm	460f	520	460	460
Electrical conductivity, min	pS/m	25g	-	-	-
Stability to oxidation, max	mg/100mL	2.5	-	-	-

a. Usually colorless to yellowish, can present slight alterations to tones of brown and orange from the addition of biodiesel.
b. Applicable to importations.
c. Limits are applicable to distribution.
d. A tolerance of 5 mg/kg will be allowed in the specified limit for inspection purposes.
e. Because of large regional variations, differentiated limits are adopted by state throughout the year (Table II of RANP 50/2013).
f. The specified limit refers to the result obtained by Standard ISO 12156. If ASTM D6079 is used, the limit of 520 µm should be adopted.
g. The analysis of the conductivity of Diesel S500 should be made after the addition of antistatic additive and coloring in the amount of 20 mg/kg.
h. Diesel 1-D/2-D should meet the minimum cetane number or the total hydrocarbon content.
i. When a dew point below -12ºC is specified, the combination of 1-D and 2-D is allowed. In these cases, the limits of 38ºC for the flash point and 1.77 cSt at 40º are used and the limits for T90 are not applied.
j. CEN stipulated Grades A – F for diesel used in temperate climates and Classes 0 – 4 for diesel used in severe and Arctic climates.

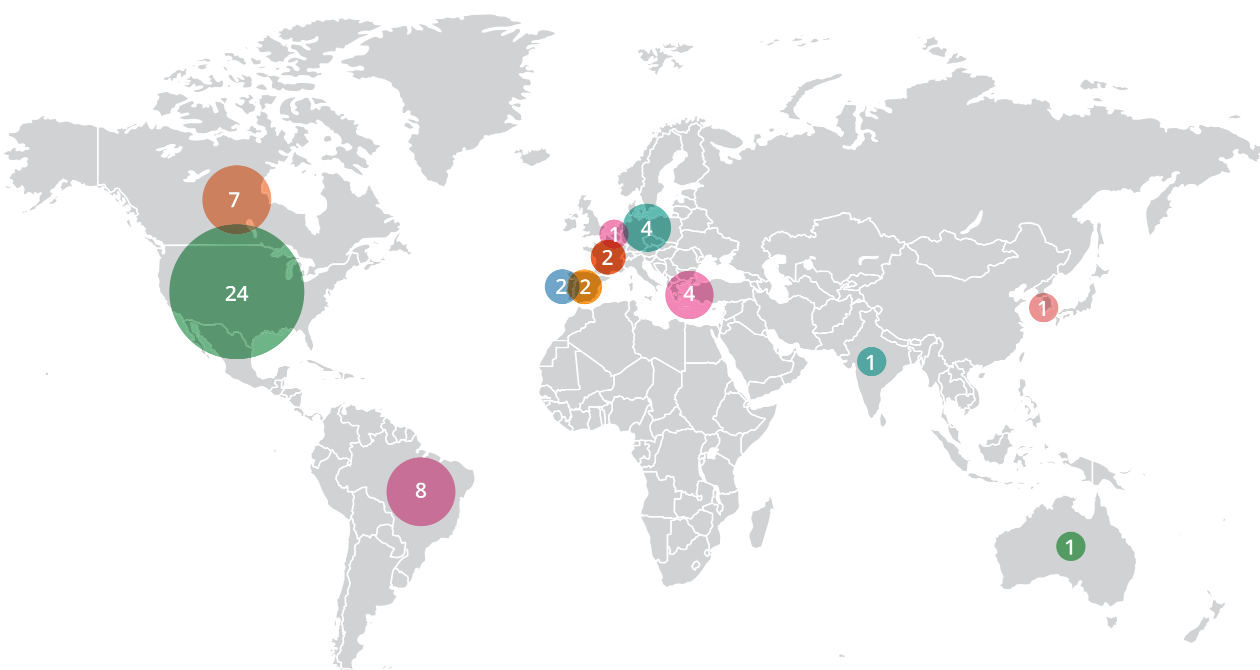
Experiments, Tests & Uses of Biodiesel in "High Blends" in Brazil and Globally

A wide range of studies covering the most diverse aspects of the use of biodiesel in blends with mineral diesel is available in Brazilian and international literature. They present analyses that consider biodiesel in different blends (BX), applied in different engines (buses, trucks, bench tests, locomotives, machinery and equipment, among others), produced from distinct raw materials (oil from soybeans, rapeseed, canola, sunflower, corn, palm, animal fats and oil residues), during a significant length of time and under different circumstances of use, storage and distribution.

The systemization of so much information came from using analysis matrices (Appendix I), which sought to extract the most relevant technical data from each of the studies consulted for this report.

In all, 57 studies, tests and analyses were part of the scope of this report. They originate in 12 different countries: U.S. (24), Brazil (8), Canada (7), Germany (4), Greece (4), France (2), Portugal (2), Spain (2), Belgium (1), Australia (1), India (1) and South Korea (1). In continental terms, there are 31 studies from North America, 15 from Europe, eight from South America, two from Asia and one from Oceania.

Figure 2: Geographic distribution of the studies used in this report



Among the studies included in this chapter, MIC (1985) presents a wide cycle of tests done by the following companies: Mercedes-Benz do Brasil, Saab Scania do Brasil, Caterpillar Brasil, Cummins do Brasil, Volvo do Brasil, Fiat do Diesel Brasil, MWM Motores Diesel and Massey Perkins. The total distance travelled was over 865,000 km and the items evaluated included clogged injector nozzles, drivability, performance, fuel consumption and maintenance costs when using B30 (blend of 70% diesel, 30% methyl ester) or, in some cases, B100.

Schumacher and Madzura (1994) compare the parameters for fuel consumption, emissions, maintenance costs and alterations in the lubricant of ten urban buses in the United States. Over 26 months, five buses were fueled with a B20 blend and five with D22 diesel, driving an average of 140,000 km.

Gateau (2006) presents the results obtained in France. The tests, which lasted 12 years (1993 to 2005), derived from a fleet of 20 trucks with EURO 0 to EURO III technology, ten of which were fueled with B50 made from rapeseed and the other ten were fueled with traditional diesel. They travelled a total distance of over 13 million kilometers and five of the engines were taken apart at the end of the tests. Among the items evaluated were fuel consumption, alterations in cold starts, and the durability and wear of components.

Proc et al. (2006) report on the study made in the U.S. between 2004 and 2006, with a fleet of nine buses fueled with B20 from soy oil. Each vehicle travelled about 160,000 km, and the impacts on fuel consumption, emissions, power and performance of the engines, alterations in cold starts, and the durability and wear of components were evaluated. As a control sample, the authors fueled the bus fleet with B0, i.e., with diesel free of biodiesel.

Barnitt et al. (2008) estimate the impact from using B20 in the variables: fuel consumption, maintenance costs, durability and wear of components, and alterations in the lubricant. The tests used seven urban passenger vehicles that ran on diesel with a very low sulphur content and eight vehicles that ran on B20, each with an initial distance travelled between 138,000 km and 214,000 km. In the twelve months of the study, the buses travelled over 1.1 million kilometers.

Castellanelli et al. (2008) analyze the performance of a diesel cycle engine in a dynamometer bench, using blends of biodiesel and diesel varying from 2% to 100%..

In its turn, FETRANSPOR (2011) analyzes the performance of 14 buses fueled with B20 and eleven fueled with diesel B in Rio de Janeiro. In twelve months, 1.1 million kilometers were travelled, getting results on fuel consumption, durability and wear of components, and alterations in the lubricant.

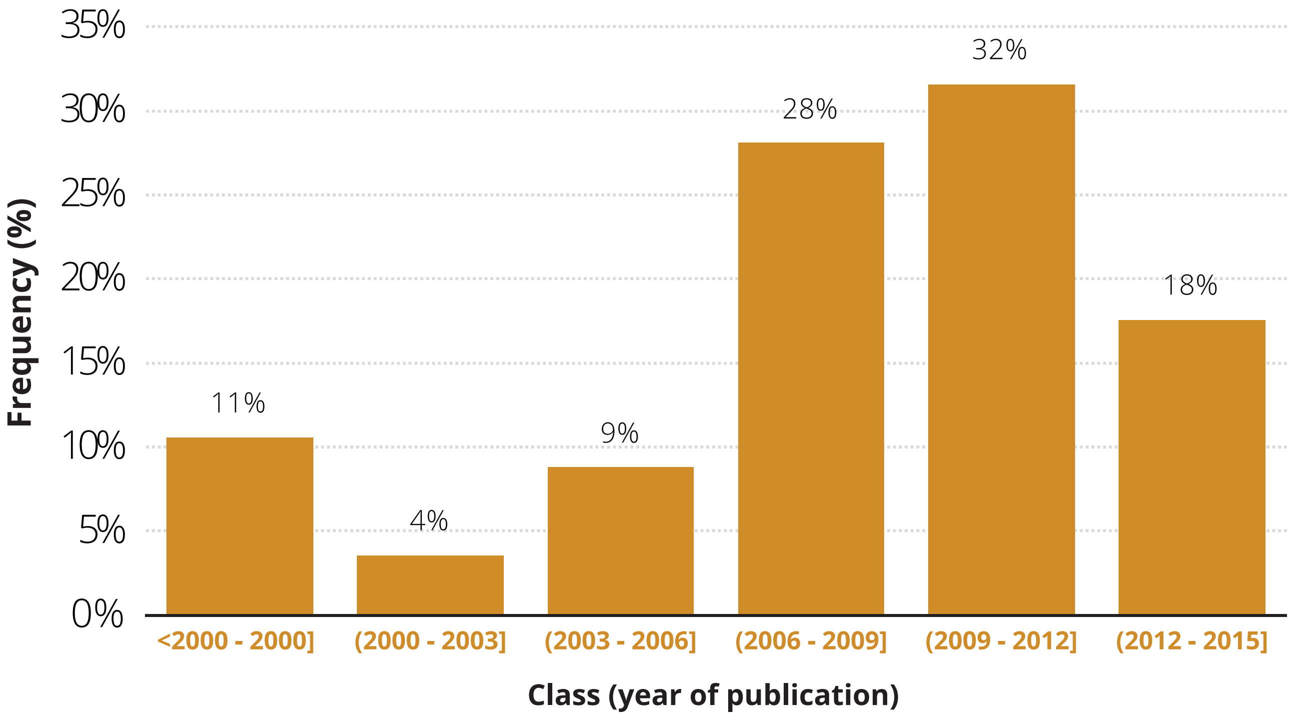
ANP (2014) gives an overview of results covering the variables: fuel consumption, emissions, cold starts, durability and wear of components, and power and performance. The tests, developed by the companies Companhia Vale do Rio Doce S.A., Camargo Corrêa, Martin-Brower, Urbanização de Curitiba S.A. (URBS), Auto Viação Redentor, Viação Cidade Sorriso Ltda. and by the Laboratory for Development of Clean Technologies of the University of São Paulo (LADETEL/USP), included vehicles from urban passenger buses through locomotives and industrial machinery and equipment. B10, B20, B25 and B100 blends were analyzed in these studies.

2 D2 diesel has characteristics that are similar to the diesel A S10 specified by ANP No. 50/2013 for trading on the domestic market.

Petrobras (2014) analyzes the use of B20 in Ford pick-up trucks over a total of 100,000 km, in a 12-month cycle of tests.

Temporally, 11% of the studies analyzed were published up to and including the year 2000, 4% were published in the years 2001 to 2003, 9% in the years 2004 to 2006, 28% in the years 2007 to 2009, 32% in the years 2010 to 2012, and 18% in or after 2013.

Figure 3: Frequency of the studies analyzed according to year of publication



In summary, the studies consulted for this report can be classified according to the content of the biodiesel used, engine or vehicle tested and raw material used in accordance with Table 3 below.

Table 3: Studies consulted

Study	BX (%)	Vehicle/Engine*	Raw Material
MIC, 1985	30/100	Bus/Truck/Others	Soybeans
Schummacher and Madzura, 1994	30	Bus	Soybeans
Howes and Rideout, 1995 (a)	20	Bus	NI
Howes and Rideout, 1995 (b)	20	Bus	NI
Bickel and Strebig, 2000	20	Truck	Soybeans
Chase et al., 2000	50	Truck	Soybeans
EPA, 2002	0 to 100	Bus/Truck/Others	Soybeans/Rapeseed/Canola/Animal Fat/Others
Lagace et al., 2003	20	Bus	Soybeans/Rapeseed/UCO/Animal Fat
Fraer et al., 2005	20	Truck	Soybeans
McCormick et al., 2005	20/100	NI	Soybeans/UCO/Animal Fat
Gateau, 2006	50	Truck/Others	Rapeseed
Munack et al., 2006	20	Bus	Rapeseed

Table 3: Studies consulted (cont.)

Study	BX (%)	Vehicle/Engine*	Raw Material
Proc et al., 2006	20	Bus	Soybeans
Chan, 2007	20	Truck/Others	Soybeans/Animal Fat
McQueen, 2007	20	Truck	Soybeans
Rhodes, 2007	20	Truck	Soybeans
Schiavone, 2007	20	Truck/Others	Soybeans/Others
Steinmetz, 2007	20	Others	Soybeans/Animal fat/Others
Barnitt et al., 2008	20	Bus	NI
Castellanelli et al., 2008	20/30/50/100	Bench	Soybeans
Kong and Kimber, 2008	20/100	Others	NI
Erhan et al., 2009	B10/B20/B30/B100	Others	Soybeans/Rapeseed/UCO/Animal fat/Others
Faraj, 2009	20	Truck/Others	Soybeans/Sunflower/Animal fat
Knuth and Winkler, 2009	30/100	Bus	Soybeans
Lujan, 2009	30/50/100	Others	NI
MCT, 2009	20	Truck/Others	Soybeans
Rakopoulus and Giakoumis, 2009	100	Truck	Soybeans
Valtra, 2009	50/100	Tractor	Soybeans/Animal fat
Yanowitz and McCormick, 2009	20	Truck	NI
Durbin et al., 2010	20	Others	Soybeans/UCO/Animal fat
Kousoulidou et al., 2010	10	Light	Rapeseed/Palm
Moscherosch et al., 2010	100	Light	Soybeans
Peterson et al., 2010	20	Others	NI
B100 Energy, 2011	20	Bus	Animal fat
Fetranspor, 2011	20	Bus	Soybeans
Kulkarni et al., 2011	20/50/100	Irrigation Equipment	Animal fat/Corn
Li et al., 2011	20	Light	Soybeans
Osborne et al., 2011	20/100	Locomotive	Soybeans
Traviss et al., 2011	20	Others	Soybeans
Giakoumis et al., 2012	0 a 100	Others	Soybeans/Rapeseed/Palm/Others
Grasman and Sadashivan, 2012	20	Bus/Others	NI
Hubert, 2012	30/100	Others	Rapeseed
McCormick, 2012	20	Truck/Others	Soybeans
Serrano et al., 2012, (a)	20/30	Bus	Soybeans/Canola
Serrano et al., 2012, (b)	20	Others	Soybeans/Palm
Shurland et al., 2012	20	Locomotive	NI
Tziourtzioumis and Stamatelos, 2012	70	Others	Soybeans/UCO/Rapeseed
VN Engineers, 2012	20	Bus	Soybeans/UCO
Anthonis et al., 2013	30	Bus	NI
Chavez, 2013	20	Others	Soybeans
Winkler et al., 2013	100	Tractor	NI
ANP, 2014	20/25/100	Bus/Truck/Others	Various
Bari, 2014	20	Bus	Canola
Broatch et al., 2014	50/100	Light	Soybeans/Rapeseed
Lim et al., 2014	20	Others	Rapeseed/Others
Petrobras, 2014	20	Light	NI
Lahane and Subramanian, 2015	20/25/50/100	Bench	NI
Tinprabath et al., 2015	20/50/100	Others	Rapeseed

** 'Others', in the 'Vehicle/Engine' column, includes other unclassified circumstances.*

NB: NI = Not Informed; UCO = Used Cooking Oil

The results, estimated in terms of the impacts from using more biodiesel, were divided into five variants, as follows:

- **Fuel consumption:** comparison of data from fleets fueled with different blends of diesel/biodiesel;
- **Emissions:** direct and indirect emission data from engines fueled with diesel and/or biodiesel are presented;
- **Cold starts:** item that reports the impacts of biodiesel on engine start-ups in cold weather;
- **Power and performance of the engine:** evidence is sought of alterations, or otherwise, in the engine's power and performance when fueled with blends with different biodiesel content;
- **Durability and wear of components:** topic which investigates whether significant alterations exist in terms of the engine's durability and wear of components in accordance with the fuel use.

Fuel Consumption

Brazil

The studies based on B20 show heterogeneous results in respect of fuel consumption levels. Castellanelli et al. (2008), MCT (2009)3, FETRANSPOR (2011) and Petrobras (2014)4 show a fall in fuel consumption when using B20, of between 0.1% and 8.83%. On the other hand, MCT (2009)5 and Petrobras (2014)6 estimate increased consumption when using B20, of between 2.5% and 4.6%. Faraj (2009) does not observe any alteration in consumption with the use of B20.

For MIC (1985), the specific consumption is the same, when comparing the use of B30 with B0. Castellanelli et al. (2008) also ran tests with B30 and their results show increased consumption with the use of this biofuel: on average, the fleet supplied with B30 consumed 3.8% more fuel that the control fleet. When releasing the results of the analyses made by Companhia Vale do Rio Doce S.A. with B25 in locomotives, ANP (2014) reports an intermediate level (an increased consumption of 2% when using the biofuel).

Castellanelli et al. (2008) compare the use of B100 with diesel A, indicating that the fleet fueled with biodiesel consumed, on average, 12.6% more fuel compared to that using traditional diesel. Valtra (2009) indicates similar levels, with an increased consumption of 13.5%. ANP (2014) shows less favorable results for the biofuel, with increases in consumption between 8% and 10% using B100 compared to traditional diesel.

Global

For Schumacher and Madzura (1994), the fleet using B20 showed a fuel consumption 3.0% greater than the fleet using diesel D2, a similar result to that obtained by Rhodes (2007), Barnitt et al. (2008), Osborne et al. (2011) and Serrano (2012)7, whose results show an increase in specific consumption varying from 1.7% to 3.7%. However, Serrano (2012)8 and Chavez (2013) show a reduction in consumption of 4% and 1%, respectively.

Other authors, such as Bickel and Strebig (2000), Fraer et al. (2005), Lagace (2005), Proc et al. (2006) and

3 Tests with off-road engines.
4 Tests with Ford Transit, urban use.
5 Tests by Mercedes-Benz.
6 Tests with Ford Ranger, both urban use and off-road.
7 Tests with non-urban use.
8 Tests with urban use.

Chan (2007), defend the lack of consistent differences in terms of consumption when comparing the use of B20 with traditional diesel.

Comparing the B50 blend with pure diesel, Chase et al. (2000) and Gateau (2006) respectively point to the same consumption and an increase of 3.4%.

In studies with B30, Serrano (2012) gets antagonistic results, depending on the modality: for urban use, there is a fall of 6.6% in consumption in the fleet supplied with B30; in non-urban use, there is an increase of 3.2% in consumption. Anthonis et al. (2013) defend the same consumption of B30 and traditional diesel.

Knuth and Winkler (2009) estimate that the use of B100 raises specific consumption by 12%, compared with common diesel.

Emissions

Brazil

As part of the validation program for the B5 blend, the emissions of soybean biodiesel produced by the ethylic and methylic methods were tested. The average results indicate an increase in emissions of NOx (B20: +4.2%; B50: +13.6% and B100: +19.2%) and a reduction in particulate matter (B20: -11%; B50: -23% and B100: -39%).

ANP (2014), citing data from tests by URBS of emissions from engines using B100, observes an increase of 19% in NOx and a reduction of 63.7% in particulate matter when compared to emissions from petroleum diesel. Periodically, the company monitors the opacity issued by the fleet's buses. The vehicles fueled with B100 had an opacity between 69% and 73% lower than that of similar vehicles fueled with S10. For hybrid vehicles, which already meet the PROCONVE P7 specifications, the reduction reached 80%.

According to FETRANSPOR (2011), there is a reduction in opacity between 11% and 39% when using B20 in public passenger transport buses. These reductions in the opacity index confirm, even if indirectly, the reduction in emissions of particulate matter.

Valtra (2009), in tests using B50 and B100 blends in tractors, found a reduction in emissions of NOx (-12.4%) and HC (-25.7%) and the same CO emissions when using B50. With B100, NOx emissions showed an increase of 11.4%, while emissions of HC and CO showed significant reduction (-45.6% and -17%, respectively). In respect of opacity, a B50 blend brought a reduction, on average, of 16.39%, while using pure biodiesel (B100) reduced soot emissions by 49.58%.

Companhia Vale do Rio Doce S.A., in tests using B25 in locomotives, found an increase of 0.6% in NO emissions and a reduction of 9.7% in CO emissions (ANP, 2014)..

Global

Giakoumis et al. (2012) carried out an extensive bibliographic review of the studies that evaluated the effect of biodiesel on the emissions from diesel cycle engines, mainly in bench tests, according to different cycles and using biodiesel from different oilseeds and fats. Generally speaking, an increase in biodiesel content tends to reduce emissions of particulate matter, hydrocarbons and carbon monoxide, while showing small increases in NOx emissions. Yet the review shows that emissions are influenced by the engine's operating conditions, as well as by the biodiesel content. The results found by Giakoumis are similar to those presented in EPA (2002).

The reduction in particulate matter emissions was seen in studies such as those by Moscherosch et al. (2010), Chase et al. (2000) and Osborne et al. (2011). Traviss et al. (2011) expanded their evaluation and even identified a reduction in the emission of fine particulates with the use of biodiesel.

NOx emissions are strongly dependent upon the engine's operating conditions, the freight and the rotation. This influence is seen in the variation of reported results. Serrano (2012) analyzes the emissions from buses in two systems with different uses, urban and extra-urban, where it was possible to identify both the increase and the reduction in NOx emissions, depending on the operating conditions.

Proc et al. (2006), when evaluating emissions according to the CSHVC (city suburban heavy vehicle cycle), observe a reduction in NOx emissions, as well as a difference in results among drivers. Anthonis (2013) cites a study with measurements made of urban buses under real conditions, where the results suggest a possibility of reduction in NOx emissions. Schumacher and Madzura (1996) and Kulkarni (2011) do not identify alteration in NOx emissions, while McCormick (2012) emphasizes a drastic reduction in NOx emissions in engines with catalytic converters, such as those in PROCONVE P7 engines. In their studies, no damage or loss of efficiency of the catalysts was seen, even after 240,000 km in tests with B20.

Osborne et al. (2011) and Shurland et al. (2012), testing the use of biodiesel in locomotives, confirm the tendency of a reduction in emissions of particulate matter, hydrocarbons and carbon monoxide under real operating conditions and following the line-haul and switch standard test cycles. For NOx, Shurland et al. (2012) emphasize that the equipment tested with B20 met EPA specifications for both cycles, while Osborne et al. (2011) identified an increase in NOx emissions only in the line-haul cycle.

Cold starts

Brazil

In Brazil, Petrobras carried out a specific study of starts at low temperatures in four Ford Rangers (EURO IV), driving with B20 at -1oC. No alteration was observed in comparison with fossil diesel (Moreira and Maia, 2014).

Global

Generally, even in countries with colder climates than Brazil, starting problems with a cold engine are only reported for blends above B50. In France, over 20 heavy vehicles and 14 light vehicles with B50 were monitored from 1993 to 2005 (Gateau, 2006). In those 12 years, Volvo and Scania heavy vehicles and Peugeot and Citroën light vehicles, which met the EURO 0, EURO I, EURO II and EURO III standards, were duly monitored and presented no cold-start problems.

In Minnesota, U.S., which has a very harsh winter, six Ford LT9000 trucks travelled with B20 for about 220,000 km and also had no problem (Bickel and Strebig, 2000).

Over 40 vehicles from different manufacturers in Vancouver, Canada, were comprehensively monitored. The fleet in the study totalled about 8 million kilometers using B20, in 2005 and 2006. Even in the winter, no problems were reported.

CARB (California Air Resources Board) carried out a study involving over 40 fleet vehicles from several U.S. states, using B20, B50 and B100. Vehicles with International/Navistar engines, General Motors, Perkins, Mercedes-Benz, Volkswagen, MAC, Thomas Built, Volvo, Isuzu, John Deere, Caterpillar, Cummins, Ford, Detroit Diesel and Freightliner were monitored, and no problems with cold starts were detected when using B20 and B50. When using B100, additives are recommended in the winter (Durbin et al., 2010).

Injection at low temperatures of around -8oC was evaluation with B20, B50 and B100, using a Bosch CRI 3.1 piezoelectric injector in several diesel engines. No alteration was observed when compared to the injection of fossil diesel (Tinprabath et al., 2015).

A study at the University of Valencia (Spain), using various blends from B20 to B100 in Euro V light vehicle engines with direct injection and common rail, concluded that cold starts with B100 could generate alterations in the mass flow of fuel, thus affecting combustion. During the European winter, the use of B50 as a maximum was recommended (Broatch et al., 2014).

Cold starts can also affect particulate emissions differently. This was the conclusion of Rakopoulos and Giakoumis (2009) in heavy truck engines with B100. In cold starts, a reduction of 63% in particulate emissions was observed when compared to diesel without biodiesel. In hot starts, this reduction was 66%.

Power and Performance

Brazil

When using B100, both MCT (2009) and Castellanelli et al. (2008) observe minor impacts of loss in power and torque. According to the first study, the result is expected because of biodiesel's lower calorific power compared to mineral diesel. MIC (1985), in tests with Caterpillar Brasil, does not show any impacts in power and performance. Castellanelli et al. (2008) also recorded small losses in power and torque when using B50.

MIC (1985), reporting on tests by Cummins, Volvo and Fiat, does not show any reduction in power and performance when using B30. On the other hand, tests done by MWM and Massey Perkins recorded intermediate impacts in these same items. ANP (2014), reporting on tests with B25 in the locomotives of Companhia Vale do Rio Doce S.A., does not indicate a loss in performance due to the use of higher biodiesel content.

Several other Brazilian studies broach this matter related to the use of B20. B100 Energy (2011), FETRANSPOR (2011) and ANP (2014) claim there is no loss of power and performance in such conditions, while Petrobras (2014), in tests with Ford Rangers, records a small loss in performance compared to the use of mineral diesel.

Global

In the international scenario, Knuth and Winkler (2009) and Lahane and Subramanian (2015) describe a drop in performance and torque of 9% and 2.76%, respectively, when comparing the use of B100 and common diesel.

For lower biodiesel blends, Lahane and Subramanian (2015) record a loss of 0.9% in the torque of engines using B20. On the other hand, Lujan (2009) – analyzing the use of B30 – and the studies by Bickel and Strebig (2000), Lagace et al. (2003), Proc et al. (2006), Faraj (2009), Durbin et al. (2010), Chavez (2013) and Bari (2014) do not indicate any impact on the power and performance of diesel cycle engines using B20.

Durability and Wear of Components

Brazil

In a similar way, when dealing with the topic 'Power and Performance', there are few cases and relatively minor potential impacts when using more biodiesel in terms of durability and wear of the components of diesel engines.

MIC (1985) describes minor impacts, such as deposits on pistons, cylinder heads and injector nozzles, when using B100 in Mercedes-Benz buses. Other than these effects, tests by Fiat, Mercedes-Benz trucks, MWM Motores Diesel and Massey Perkins, these last using B30, also show wear in the cylinders.

On the other hand, the same study does not show an impact in tests with B30 done by Cummins and by Volvo, and the same conclusion was reached using B100 in Saab/Scania and Caterpillar equipment (MIC, 1985).

When dealing with B30, MCT (2009) reports there were no impacts in tests developed by Peugeot/Citroën, the sane result as that obtained using B20 in Camargo Corrêa and Martin-Brower equipment.

FETRANSPOR (2011) does not observe any impacts in the durability of the components when using B20 in metropolitan passenger buses.

ANP (2014) records the need for more frequent fuel-filter changes when using B20 in off-road engines, as well as no undesirable impacts on the durability and wear of components in tests done by Camargo Corrêa and by LADETEL.

Finally, Petrobras (2014) indicates good results when using B20 in its Ford Ranger and Transit fleets. In the first case, a little wear in the cylinder walls was the only impact noted, while in the case of the Transits no impact was observed.

Global

Among the international studies consulted in this document, Winkler et al. (2013) show small accumulations of elements and reduction in the periods between oil changes when using B100.

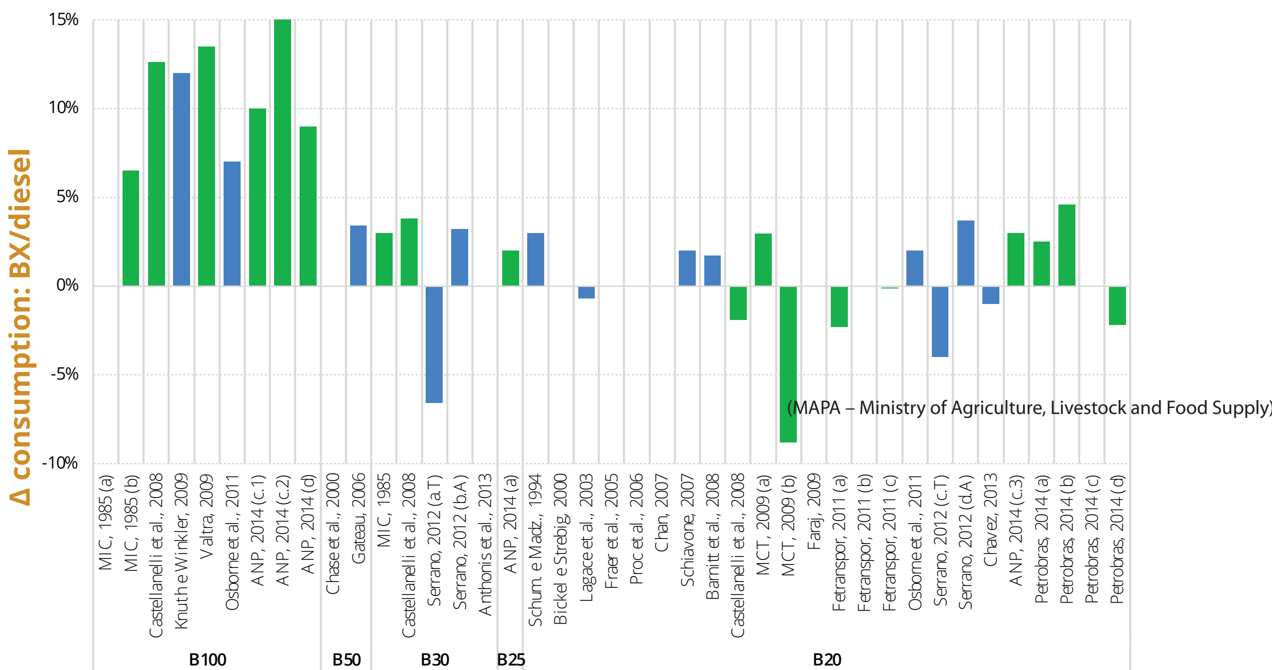
Regarding the use of B50, Chase et al. (2000) and Gateau (2006) converge in terms of results, stating that there are no negative impacts in the durability and wear of components in the engines analyzed.

Lagace et al. (2003) and Fraer et al. (2005) cite a need to change fuel filters and injector nozzles more frequently when using B20, an effect the authors consider of little significance. Bickel and Strebig (2000), Proc et al. (2006), Barnitt et al. (2008) and Durbin et al. (2010) do not record any negative impacts in durability.

The following Figures 4 to 6 and Table 4 systematize the main results obtained from the studies consulted for this report. The green highlights relate to information collected from Brazilian literature.

As regards the differences in fuel consumption among the tests using high blends and conventional diesel, as expected, lower average elevations were seen as the biodiesel content fell (Figures 4 and 5). On average, the studies on B100 show a consumption 9.5% higher in comparison with conventional diesel, varying from a minimum of 0% to a maximum of 15%.

Figure 4: Fuel consumption – variation in consumption due to the use of "high blends" of biodiesel in relation to traditional diesel



MIC, 1985 (a): Mercedes Benz do Brasil (bus)

MIC, 1985 (b): Saab/Scania do Brasil

MCT ,2009 (a): Mercedes-Benz

MCT ,2009 (b): Testes com motores off-road

FETRANSPOR, 2011 - (a): Rodoviária A. Matias

FETRANSPOR, 2011 - (b): Real Auto Ônibus

FETRANSPOR, 2011 - (c): Viação Ideal

Serrano, 2012 (a.T): urban use

Serrano, 2012 (b.A): non-urban use

Serrano, 2012 (c.T): urban use

Serrano, 2012 (d.A): non-urban use

Petrobras, 2014 (a): Ranger, highway use

Petrobras, 2014 (b): Ranger, city use

Petrobras, 2014 (c): Transit, highway use

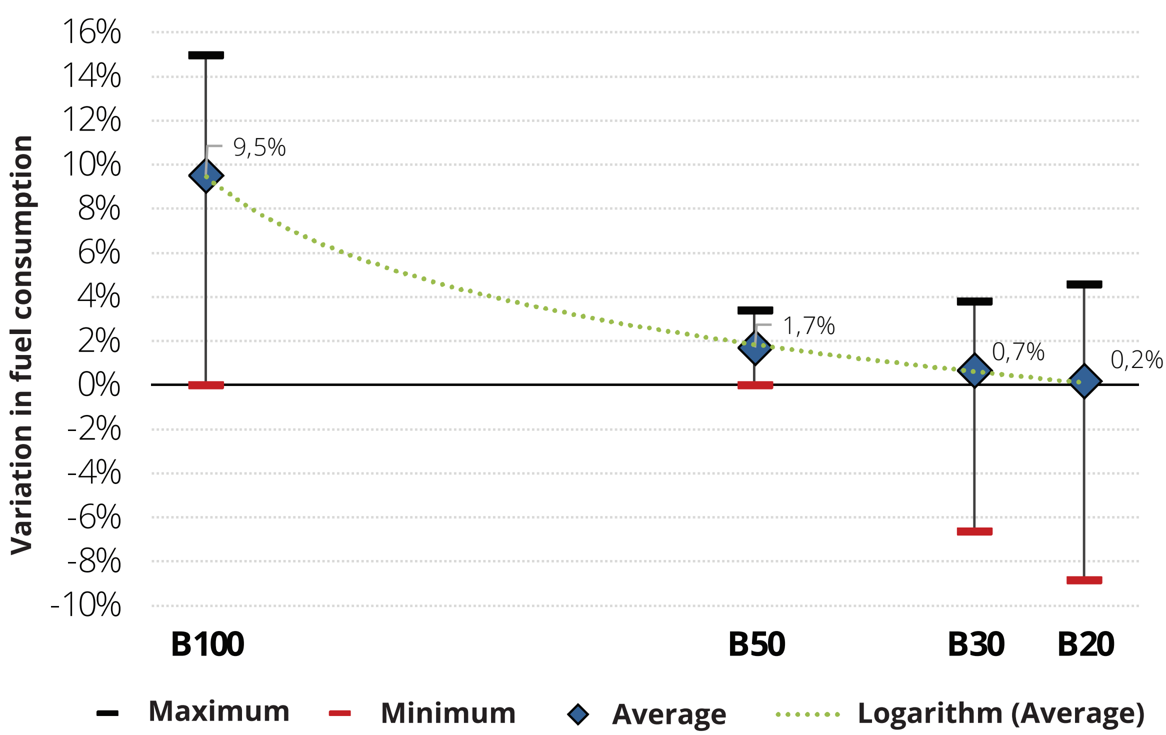
Petrobras, 2014 (d): Transit, city use

When using B50, the increase of consumption is between 0% and 3.4%, with an average of 1.7%, The results computed from the use of B30, in its turn, show an average increase of 0.7% in fuel consumption, with significant variation (from -6.6% to 3.8%), while tests with B20 show a variation in consumption between -8.8% and 4.6%, with an average of 0.2%.

Among the justifications for the tendency observed is the lower calorific power of biodiesel in relation to diesel (thus raising the unit fuel consumption of the former). In contrast, the biofuel's greater specific mass can, at times, act to restrict the extent of the fuel consumption increase, in view of the fact that, in the same volume of fuel, there is a larger mass of biodiesel in relation to mineral diesel.

Nevertheless, the relatively high variance observed proves the difficulty of getting homogenous and compatible estimates for the purpose of making a decision. While the use of standard methodologies to evaluate the consumption controls various parameters in such a way as to obtain reproducible results, these controls lead to conditions that diverge from the vehicle's real use. On the other hand, the adoption of methodologies that reproduce real situations leads to results that are probably coherent within the study, but are difficult to compare with other studies.

Figure 5: Fuel consumption – variation in consumption by range of diesel-biodiesel blend



The balance of direct emissions from biodiesel when compared to mineral diesel is positive. Agreeing with the EPA (2002) study, the use of B20 generates significantly lower emissions of carbon monoxide (CO), hydrocarbons (HC) and particulate matter (PM), compared to a small increase in nitrogen oxide (NOx) emissions.

Considering the use of B20, on average, the studies consulted for this report recorded a reduction of around 20% in CO emissions, varying from 53% to 4%. Similar levels were observed in the reduction of PM emissions (an average of -23%, with a minimum of -5% and a maximum of -47%). In the case of hydrocarbons, the average reduction was 28% (varying from a minimum of 10% to a maximum of 60%).

In the case of NOx, a small increase in emissions, of around 3%, was observed when using B20 to the detriment of pure fossil diesel. Notwithstanding reports of increased emissions at levels above 20%, there are cases where a reduction in NOx emissions of as much as -5% was reported.

Figure 6: Variation in emissions of carbon monoxide (CO), hydrocarbons (HC), particulate matter (PM) and nitrogen oxides (NOx) when using B20

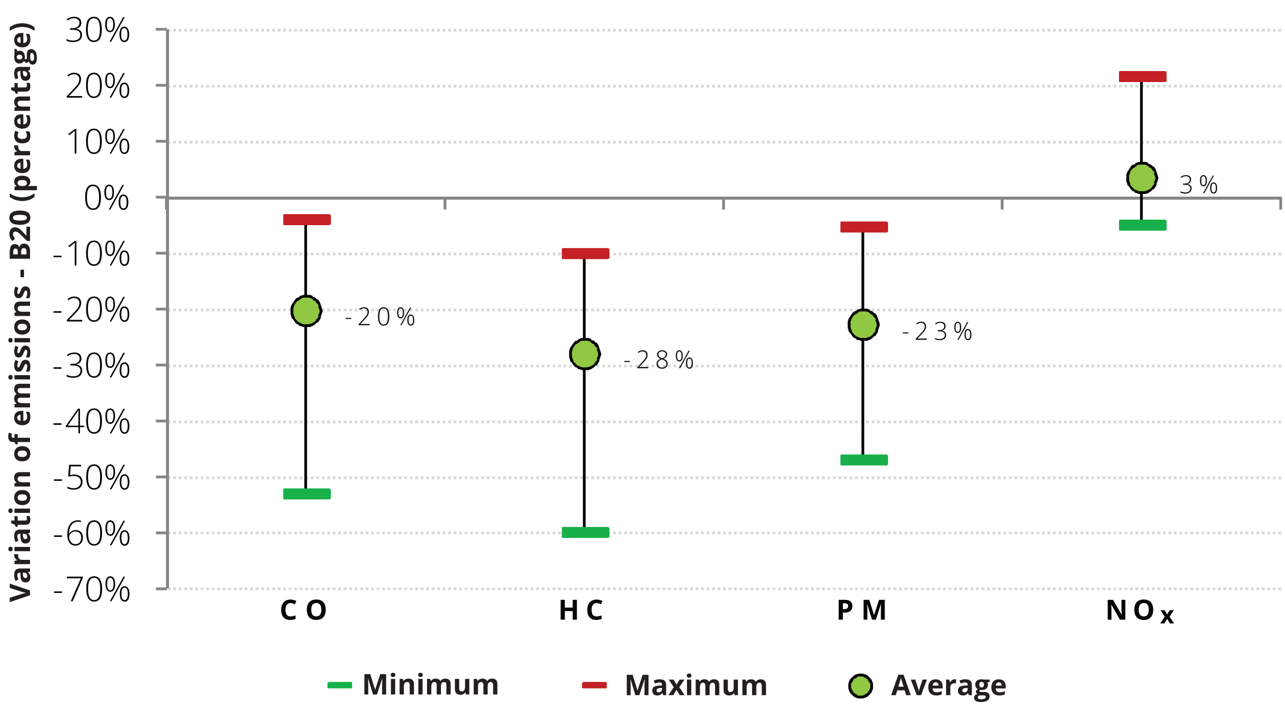


Table 4 is a summary of the results for the items “Cold Starts”, “Power and Performance” and “Durability and Wear of Components”.

Reservations regarding “Cold Starts” are rare; the limitations are restricted to environments with negative temperatures, which are not applicable to the Brazilian market.

For the item “Power and Performance”, the results are notably insignificant when comparing the use of B20 with conventional diesel. In these cases, there are a few reports of a loss in power and torque but the majority of the studies do not record negative impacts from using more biodiesel. There even are some cases where an increase in power was recorded. As the biodiesel content in the diesel blend increases, a reduction in power and a fall in performance becomes more common.

Finally, there are few losses attributable to biodiesel in the item "Durability and Wear of Components". Briefly, the changes of fuel filters and some other components were more frequent.

The studies consulted for this report converge as regards the need to have best practices throughout the fuel production and distribution chain, paying special attention to the proper procedures for handling, transporting and storing the biodiesel and mineral diesel consumed by the automotive market. A not insignificant range of the problems presented here are a result of the poor operating conditions observed. Furthermore, it is a fact that the specifications for mineral and renewable fuels must be complied with throughout their useful lives; in other words, the quality of the product plays a major role in the good running of diesel cycle engines.

Table 4: Cold Starts, Power & Performance, and Durability & Wear of Components – results of the studies consulted for this report

BX	Study	Cold Starts	Power & Performance	Durability & Wear of Components
B100	MIC, 1985 (a)			Presence of moderate whitish deposits on pistons, cylinder heads and injector nozzles
	MIC, 1985 (b)			No impact
	MIC, 1985 (c)		No impact	No impact
	Knuth e Winkler, 2009		Loss of performance of 9%	
	MCT, 2009 (c)		Slight loss of performance due to lower calorific power of biodiesel	
	Castellanelli et al., 2008		Slight loss of power and torque	
	Valtra, 2009		Slight loss of power	Slight presence of deposits on pumps and more frequent oil changes
	Winkler et al., 2013			Small accumulations of elements and reduction in periods between oil changes
	Broatch et al., 2014	Alterations in mass flow of fuel		
	Lahane e Subramanian, 2015		Loss of 2.76% in torque	
B50	Chase et al., 2000		No impact	No impact
	Gateau, 2006	No impact		No impact
	Castellanelli et al., 2008		Slight loss of power and torque	
	Broatch et al., 2014	Maximum limit: B50		
B30	MIC, 1985 (d), (e)		No impact	No impact
	MIC, 1985 (f)		No impact	Slight presence of deposits on injector nozzles
	MIC, 1985 (g)			Clogged injector nozzle orifice, wear and abnormal ovalization of the cylinders
	MIC, 1985 (h), (i)		Loss of performance and power	Deposits on and blockage of injector nozzles, erosion of pistons and adverse wear
	Lujan, 2009		No impact	
	MCT, 2009 (a)			No impact
	Serrano, 2012			
B25	ANP, 2014 (a)		No impact	No impact

Table 4: Cold Starts, Power & Performance, and Durability & Wear of Components – results of the studies consulted for this report (cont.)

BX	Study	Cold Starts	Power & Performance	Durability & Wear of Components
B20	Bickel e Strebig, 2000	No impact	No impact	No impact
	Lagace et al., 2003		No impact	Greater change of fuel filters
	Fraer et al., 2005			No significant impact; possible higher frequency in changes of injector nozzles and fuel filters
	Proc et al., 2006		No impact	No impact
	Chan, 2007	No impact		
	McQueen, 2007	No impact		
	Schiavone, 2007			Greater change of fuel filters and injector nozzles
	Barnitt et al., 2008			No impact
	Castellanelli et al., 2008		Increase in power and slight loss of torque	
	Faraj, 2009		No impact	
	MCT, 2009 (b), (c)			No impact
	Durbin et al., 2010	Use of additives or change in blend at very low temperatures	No impact	No impact
	B100 Energy, 2011		No impact	
	Fetranspor, 2011	No impact	No impact	No impact
	Traviss et al., 2011			
	Chavez, 2013		No impact	
	ANP, 2014 (b), (e)		No impact	No impact
	ANP, 2014 (c)		No impact	Greater change of fuel filters
	Bari, 2014		No impact	
	Petrobras, 2014 (a)	No impact	Slight loss of performance	Slight wear in cylinder walls
	Petrobras, 2014 (b)	No impact		No impact
	Lahane e Subramanian, 2015		Slight fall (0.9%) in torque	
	Tinprabath et al., 2015	No impact		

MIC, 1985 (a): Mercedez-Benz do Brasil (ônibus)
MIC, 1985 (b): Saab/Scania do Brasil
MIC, 1985 (c): Caterpillar Brasil
MIC, 1985 (d): Cummins do Brasil
MIC, 1985 (e): Volvo do Brasil
MIC, 1985 (f): Fiat Diesel Brasil
MIC, 1985 (g): Mercedez-Benz do Brasil (caminhão)
MIC, 1985 (h): MWM Motores Diesel
MIC, 1985 (i): Massey Perkins

MCT, 2009 (a): Teste Peugeot/Citroën
MCT, 2009 (b): Teste Mercedez-Benz
MCT, 2009 (c): Teste com motores off-road
ANP, 2014 (a): Companhia Vale do Rio Doce S.A.
ANP, 2014 (b): Camargo Corrêa S.A.
ANP, 2014 (c): Martin-Brower Comércio
ANP, 2014 (e): LADETEL/USP
Petrobras, 2014 (a): Ranger
Petrobras, 2014 (b): Transit

Final Considerations

The 57 studies consulted to report the results of the tests and experiments using blends of biodiesel and petroleum diesel over 10% (>B10) were selected as being the most robust from a scientific point of view, from reliable sources and representative of Brazil's reality.

These studies are evidence of the growing interest, shown by researchers and government and private entities, in the evaluation of these blends as regards the important items for the biodiesel production chain and the end-user of the blends. After oscillating between 4% and 11% in the earlier three-year periods, 28% of the studies were made between 2006 and 2009. The following three-year period (2009-2012) accounted for 32% of these studies and the most recent period (2012-2015) for 18%.

Generally speaking, the evaluations of the diesel-biodiesel blends indicate that, up to B30, no clear tendencies could be verified regarding a variation in fuel consumption, since the results show both increases and reductions in consumption. Up to B50, the average increases observed are relatively small or insignificant, varying between 0.2% (B20), 0.7% (B30) and 1.7% (B50). Also worth mentioning is the large variation in the results for B20, which go from a reduction of 8.8% in consumption up to an increase of 4.6%. For B100, both the average (an increase of 9.5%) and the variation (increases between zero and 15%) were higher.

This variability can be explained by the nature of the experiments: while the bench test results are more reproducible because they are better controlled, experiments with vehicles on the roads suffer from the influence of factors over which little or no control is possible (traffic conditions, drivers, number of passengers, freight volume, etc.), thus tending to produce different results.

Regarding emissions, there are three aspects to highlight. The first refers to the emission levels established by PROCONVE. In their successive phases for heavy vehicles (basically trucks and buses) from P0 to P7, the maximum permitted emission limits are becoming ever more restrictive, encompassing carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NOx) and particulate matter (PM). In this aspect, the results of the studies related to Brazil and other countries show small increases in NOx and significant reductions in the other named pollutants, both increasing with the increase in blend content, resulting in a balance of emissions favorable to the high blends being analyzed.

The second aspect refers to NOx. There are studies indicating that the emissions of this pollutant are strongly dependent on operating conditions, rotation and torque of the engine, while others highlight a reduction in NOx emissions in engines equipped with catalytic converters, which as from 2012 are classified in PROCONVE's P7 phase.

The third point, in principle, involves the challenge represented by the compensatory effect between emissions of NOx and of PM. In general, the engine's operating conditions that reduce particulate matter emissions tend to increase the emissions of nitrogen oxides, and vice versa.

When it comes to tests related to difficulties with cold starts, there were few reservations identified in the studies, other than those restricted to low-temperature environments, of little pertinence to the Brazilian market. Furthermore, the requirements established by ANP regarding the cold clogging point, stricter in the winter months, tend to be sufficient to prevent any problems in this item.

Engine power and performance was another item researched in the selected studies, and these results were similar to those related to consumption: reduction of power and loss of performance are more frequent with blends richer in biodiesel, though there are also tests that indicate an increase, rather than a reduction, in power. In general, the studies consulted do not register significant impacts on the engine's power and performance when using biodiesel blends, as compared to fossil diesel, especially in the case of B20.

As regards durability and wear of components, in general, the studies consulted do not register significant losses from the use of diesel-biodiesel blends, in different proportions, except for more frequent changes of fuel filters and some other components. Nevertheless, the TF considers it important to have some records in this regard, related to the biodegradable character of biodiesel.

Indeed, based on the recommendations included in some of the studies analyzed and on best practices for the storage and handling of these blends, following and improving the procedures and care that allow specific blends to maintain their quality until finally used are indicated. This step, together with the advances in more adequate materials used in contact with this biodegradable fuel, both in internal tank linings and in the manufacture of engine parts and components, tends to reduce progressively possible problems in the final use of diesel-biodiesel blends.

References

AGÊNCIA NACIONAL DO PETRÓLEO, GÁS NATURAL E BIOCOMBUSTÍVEIS – ANP. **Biodiesel**. Disponível em: <http://www.anp.gov.br/?id=472>.

AGÊNCIA NACIONAL DO PETRÓLEO, GÁS NATURAL E BIOCOMBUSTÍVEIS – ANP. **Relatório Técnico nº 02/2014/SBQ/RJ**. Apresentação dos resultados dos Testes de uso experimental e específico de biodiesel e suas misturas com óleo diesel em teores diversos do autorizado em legislação. Rio de Janeiro. 2014.*(Technical Report No. 02/2014/SBQ/RH. Presentation of test results on experimental and specific use of biodiesel and its blends with diesel in proportions other than those authorized by legislation.)*

ANTHONIS, T.; BOGAERT, I.N.A; DOBBELAERE, S.L.; SOETAERT, W.K. **Missed opportunities and lessons learned, evaluation of the initiative on B30 biodiesel in the CIVITAS project of the Belgian City Ghent**. Biomass and bioenergy 57, 191 e195, 2013.

BARI, S. **Performance, combustion and emission tests of a metro-bus running on biodiesel-ULSD blended (B20) fuel**. Applied Energy 124, 35–43, 2014.

BARNITT, MCCORMICK, R.L.; LAMMERT, M. **St. Louis Metro Biodiesel (B20) Transit Bus Evaluation**. Technical Report, NREL/TP-540-43486, July 2008.

BICKEL, K.; STREBIG, K. **Soy-Based Diesel Fuel Study**. Final report, Legislative Commission on Minnesota Resources. 2000.

BROATCH, A.; TORMOS, B.; OLMEDA, P.; NOVELLA, R. **Impact of biodiesel fuel on cold starting of automotive direct injection diesel engines**. Energy 73, 653-660, 2014.

CASTELLANELLI, M.; SOUZA, S. N. M.; SILVA, S. L.; KAILER, E. K. **Desempenho de motor ciclo diesel em bancada dinamométrica utilizando misturas diesel/biodiesel**. Engenharia Agrícola, Jaboticabal, v.28, n.1, p.145-153, jan./mar. 2008

CHAN, S. **Biofleet case study #2**. City of Vancouver, 2007.

CHAVEZ, D. **Demonstration of Biodiesel in Ground Tactical Vehicles and Equipment**, Final Report, 2013.

CHASE, C.; PETERSON, C.; LOWE, G.; MANN, P.; **A 322,000 kilometer (200,000 mile) Over the Road Test with HySEE Biodiesel in a Heavy Duty Truck**, SAE Technical Paper 2000-01-2647, 2000.

DEPARTAMENTO NACIONAL DE TRÂNSITO – DENATRAN. **Estatística**: Frota. Disponível em: <http://www.denatran.gov.br/frota.htm>.

DURBIN, T.D.; MILLER, J.W.; JIANG, S.M. **Biodiesel Fleet Durability Study**. Draft Final Report, California Air Resources Board. Sacramento, July 2010.

ERHAN, S.Z.; DUNN, R.O.; KNOTHE, G.; MOSER, B.R. **Fuel properties and performance of biodiesel**. Biocatalysis and Bioenergy, 2009.

ENVIRONMENTAL PROTECTION AGENCY – EPA. **A comprehensive analysis of biodiesel impacts on exhaust emissions**. Draft Technical Report. October, 2002.

FARAJ, L.C. **Motores diesel e uso de biodiesel**. CUMMINS Brasil Ltda. Julho de 2009. Disponível em: <http://www.aea.org.br/apresentacoes/lub08/Luis_Chain.pdf>.

FETRANSPOR - FEDERAÇÃO DAS EMPRESAS DE TRANSPORTES DE PASSAGEIROS DO ESTADO DO RIO DE JANEIRO. **Biodiesel B20 – O Rio de Janeiro anda na frente**. Rio de Janeiro. Rio de Janeiro. 2011. 104p.

FRAER, R.; DINH, H.; PROC, K.; MCCORMICK, R.L.; CHANDLER, K.; BUCHHOLZ, B. **Operating Experience and Teardown Analysis for Engines Operated on Biodiesel Blends (B20)**, 2005 SAE Commercial Vehicle Engineering Conference, 2005.

GATEAU, P. **Twelve years of using 50% RME fuel mixture in heavy trucks and light vehicles**. AEA 2006 – 5-6 April 2006 – Poitiers, Futuroscope.

GIAKOUMIS, E.G.; RAKOPOULUS, C.D.; DIMARATOS, A.M.; RAKOPOULUS, D.C. **Exhaust emissions of diesel engines operating under transient conditions with biodiesel fuel blends**. Progress in Energy and Combustion Science 38, 691-715. 2012.

GRASMAN, S.E, SADASHIVAM, S. **Implementation policy considerations for achieving year-round operability of biodiesel programs**. Biomass and bioenergy 39, 439-448, 2012.

HOWES, P.; RIDEOUT, G. **Evaluation of biodiesel in an urban transit bus powered by a 1981 DDC8V71 engine**. MSED Report #95-26743-2. Canada, 1995b.

HOWES, P.; RIDEOUT, G. **Evaluation of biodiesel in an urban transit bus powered by a 1988 DDECII6V92 TA engine**. MSED Report #95-26743-1. Canada, 1995a.

HUBERT, A. **Utilisation of the internal engine potential of biodiesel (FAME) with consideration for specific fuel characteristics in the common**

rail diesel engines. UFOP Project No. 540/122 – Final Report. September, 2012.

KNUTH, H.; WINKLER, M. **Implementation of a 500h Engine Test Cycle and Field Testing of DEUTZ-Common-Rail Engines in Heavy-Duty Euro IV Truck Applications for Release of Biodiesel**. UFOP Project No. 540/080, Final Report. Cologne, September 2009.

KONG, S; KIMBER, A. **Effects of biodiesel blends on the performance of large diesel engines**. SAE Technical Paper 2008-01-1389, 2008.

KOUSOULIDOU, M.; FONTARAS, G.; NTZIACHRISTOS, L.; SAMARAS, Z. **Biodiesel blend effects on common-rail diesel combustion and emissions**. Fuel 89, 3442-2449, 2010.

KULKARNI, S.S.; JOHNSON, D.M.; DAVIS, J.A.; KENNON, D. **Irrigation power unit performance, eficiency, and NOx emissions with petroleum diesel, biodiesel and biodiesel blends**. Applied Engineering in Agriculture Vol. 27(2): 217-222, 2011.

LAGACE, C; HOSATTE, P.; BEAUDIN, L.; BOURGAULT, C.; GOULET, M.; SOULIGNY, M.; SYLVESTRE, P.; TREMBLAY, L.Y. **Biodiesel Demonstration and Impact Assessment with the Societé de Transport de Montreal (STM)**, 2003.

LAHANE, S.; SUBRAMANIAN, K.A.. **Effect of different percentages of biodiesel–diesel blends on injection, spray, combustion, performance, and emission characteristics of a diesel engine**. Fuel 139, 537–545, 2015.

LI, M.Y.; POYNTER, M.E.; PALMER, B.C.; PARKER, E.; MOSSMAN, B.T.; HOLMEN, B.A.; FUKAGAWA, N.K. **Are Biodiesel (B20) Emissions Less Harmful than Petrodiesel (B0)?**, Free Radical Biology and Medicine, 51 (2011) S106-S106.

LIM, C.; LEE, J.; HONG, J.; SONG, C.; HAN, J.; CHA, J.S. **Evaluation of regulated and unregulated emissions from a diesel powered vehicle fueled with diesel.biodiesel blends in Korea**. Energy 77, 533e541, 2014.

LUJAN, J.M.; TORMOS, B.; SALVADOR, F.J.; GARGAR, K. **Comparative analysis of a DI diesel engine fuelled with biodiesel blends during the European MVEG-A cycle: Preliminary study (I)**. Biomass and Bioenergy 33, 941–947, 2009.

MCCORMICK, R.L. **Performance of Biofuels and Biofuel Blends**. NREL Project ID: FT003. May, 2012.

MCCORMICK, R.L.; ALLEMAN, TL.; RATCLIFF, M.; MOENS, L. S**urvey of the Quality and Stability of Biodiesel and Biodiesel Blends in the United States in 2004**. Technical Report NREL/TP-540-38836. October, 2005.

MCCORMICK, R.L.; WESTBROOK, S.R. **Storage Stability of Biodiesel and Biodiesel Blends**, Energy & Fuels, 24 (2010) 690-698.

MCQUEEN, J. **Biofleet case study #6**. Township of Langley, 2007.

MINISTÉRIO DA CIÊNCIA E TECNOLOGIA – MCT. **Testes e ensaios para validação do uso da mistura biodiesel B5 em motores e veículos**. Secretaria de Desenvolvimento Tecnológico e Inovação – Brasília: Ministério da Ciência e Tecnologia, 2009. 176p.

MINISTÉRIO DE INDÚSTRIA E DO COMÉRCIO - MIC, Secretaria de Tecnologia Industrial. **Óleos vegetais – experiência de uso automotivo desenvolvida pelo Programa OVEG I**. Brasília, STI/CIT, 1985. 344p.

MINISTÉRIO DO MEIO AMBIENTE – MMA. **Inventário nacional de emissões atmosféricas por veículos automotores rodoviários – 2013: Ano-base 2012**. Relatório Final. Brasília, 2014.

MOREIRA, M.F.; MAIA, D.M. **Impact of a 20% biodiesel in diesel blend (B20) on vehicles**. In: XXII Simpósio Internacional de Engenharia Automotiva. Blucher Engineering Proceedings, Nº 2, V. 1, agosto de 2014.

MOSCHEROSCH, B.W.; POLONOWSKI, C.J.; MIERS, S.A.; NABER, J.D. **Combustion and emissions characterization of soy methyl ester biodiesel blends in an automotive turbocharged diesel engine**. Journal of Engineering for Gas Turbines and Power, 132(9), 092806 (2010).

MUNACK, A.; KAUFMANN, A.; SCHRÖDER, O.; KRAHL, J; BÜNGER, J. **Comparision of shell middle distillate premium diesel fuel and fossil diesel fuel with repeseed oil methyl ester**. Research Project Final Report, Braunshweig, April 2006.

OSBORNE, D.; FRITZ, S.; GLENN, D. **The effects of biodiesel fuel blends on exhaust emissions from a general electric tier 2 line-haul locomotive**. Journal of Engineering for Gas Turbines and Power - Transactions of the Asme, 133 (2011) 7.

PETERSON, A.M.; LEE, P.I.; LAI, M.C.; WU, M.C.; DIMAGGIO, C.L.; NG, S.; TANG, H.Y. **Effects of B20 on emissions and the performance of a diesel particulate filter in a light-duty diesel engine**. Journal of Engineering for Gas Turbines and Power - Transactions of the Asme, 132 (2010) 8.

PROC, K.; BARNITT, R.; HAYES, R.R.; RATCLIFF, M.; MCCORMICK, R.L.; HA, L; FANG, H.L. **100,000-Mile Evaluation of Transit Buses Operated on Biodiesel Blends (B20)**. NREL/CP-540-40128. Posted with permission. Presented at the Powertrain and Fluid Systems Conference and Exhibition, October 2006, Toronto, Canada. 2006.

RAKOPOULUS, C.D.; GIAKOUMIS, E.G. **Diesel Engine Transient Operation: Principles of Operation and Simulation Analysis**. Springer-Verlag London, London, 2009. 390 p.

RHODES, C. **Biofleet case study #6**. Six BC Municipalities British Columbia, 2007.

SCHIAVONE, J.J. **Use of a biodiesel in a transit fleet: a synthesis of transit practice**. Research Sponsored by the Federal Transit Administration in Cooperation with the Transit Development Corporation. Washington, D.C. 2007.

SCHUMACHER, L.G; MADZURA, T. **Biodiesel bus data collection project**. National Renewable Eaergy Laboratory – NREL. April 14, 1994 - June 30, 1996.

SERRANO, L.M.V.; CARREIRA, B.; CÂMARA, R.; GAMEIRO DA SILVA. M.C. **On-road performance comparison of two identical cars consuming petrodiesel and biodiesel**. Fuel Processing Technology 103, 125–133, 2012.

SERRANO, L.M.V.; CÂMARA, R.M.O.; CARREIRA, V.J.R.; GAMEIRO DA SILVA. M.C. **Performance study about biodiesel impact on buses engines using dynamometer tests and fleet consumption data**. Energy Conversion and Management 60, 2–9, 2012.

SHURLAND, M.; DEITCHMAN, R.; SMITH, W. **Emissions testing of an intercity passenger locomitive operating on b20 biodiesel fuel**, Proceedings of the Asme Joint Rail Conference 2012, (2012) 745-753.

STEINMETZ, R. **Biofleet case study #7**. Cascadia Biodiesel Card Lock Station Delta, 2007.

TINPRABATH, P.; HESPEL, C.; CHANCHAONA, S.; FOUCHER, F. **Influence of biodiesel and diesel fuel blends on the injection rate under cold conditions**. Fuel 144, 80–89, 2015.

TRAVISS, N.; THELEN, B.A.; INGALLS, J.K.; TREADWELL, M.D. **Evaluation of biodiesel's impact on real-world occupational and environmental particulate matter exposures at a municipal facility in Keene, NH**, Air Quality Atmosphere and Health, 5 (2012) 101-114.

TZIOURTZIOUMIS, D.; STAMATELOS, A. **Effects of a 70% biodiesel blend on the fuel injection system operation during steady-state and transient performance of a common rail diesel engine**. Energy Conversion and Management 60, 56–67, 2012.

VALE. **Análise da viabilidade e da influência do uso de biodiesel (B25) em locomotivas da frota da Vale**. In: IV Encontro de Ferrovias ANTF. Vitória/ES. Agosto de 2013.

VALTRA. **Avaliação do motor AGCO SISU POWER após testes de durabilidade com biodiesel em tratores Valtra BH180**. Relatório Técnico nº RT 001/09. 2009.

VN ENGINEERS. **Regional school bus study: a comparison of alternative fuels for school transportation fleets**. Prepared for the South Central Regional Council of Governments, North Haven. January, 2012.

WINKLER, M.; WITTROCK, M.; KNUTH, H.W. **Long-term durability investigations of DEUTZ AGRI POWER engines in emission stage EU COM III B with SCR-system for the release of biodiesel**. Ufop-PROMOTION PROJECT No. 540-103 – Final Report. Cologne, June, 2013.

YANOWITZ, J.; MCCORMICK, R.L. **Effect of biodiesel blends on North American heavy-duty diesel engine emissions**. European Journal of Lipid Science and Technology, 111 (2009) 763-772.

Appendix I – Matrix of the Analysis Used

Identification of the Initiative			
1. Title of the Study | Year			
2. Executing Entity			
3. Country / Continent			
4. Evaluation Period | Time			Months
5. Website			
6. Characteristics of Engines Used			
7. Characteristics of Blend Used			
8. Characteristics of Biodiesel Used			
9. Evaluations Made:	Results		
a. Fuel consumption			
b. Emissions			
c. Cold starts			
d. Engine power/ performance			
e. Maintenance costs			
f. Durability/ wear of components			
g. Performance			
h. Other			
10. Final TF Comments	Field of Qualitative Scope: Summarize the utility of the initiative, opinion of the study, etc.		

ISBN 978-85-7991-097-5

MAPA
Ministério
da Agricultura
Pecuária e Abastecimento

GOVERNO FEDERAL
BRASIL
PÁTRIA EDUCADORA