



ROADMAP FOR SUSTAINABLE AVIATION BIOFUELS FOR BRAZIL

A Flightpath to Aviation Biofuels in Brazil



UNICAMP

Stakeholders:

 <p>AIAB ASSOCIATION OF INDUSTRIES ASSOCIATION OF BRAZIL</p>	 <p>AMYRIS</p>	 <p>ANAC AGÊNCIA NACIONAL DE AVIAÇÃO CIVIL</p>	 <p>ANDRITZ Pulp & Paper</p>	 <p>anp Agência Nacional do Petróleo, Gás Natural e Biocombustíveis</p>
 <p>APTta Associação Portuguesa de Transporte e Trabalho Aéreo</p>	 <p>BIOEca Brasil</p>	 <p>BYOGY RENEWABLES</p>	 <p>Climate Solutions</p>	 <p>CTBE</p>
 <p>Embrapa Agroenergy</p>	 <p>ergos tech renewable energy solutions</p>	 <p>GOL Linhas aéreas inteligentes</p>	 <p>IAE IAE</p>	 <p>ICONE Institute for International Trade Negotiations</p>
 <p>ITA</p>				 <p>LanzaTech</p>
 <p>life technologies™</p>	 <p>NESTE OIL</p>	 <p>NATIONAL WILDLIFE FEDERATION</p>	 <p>OLEOPLAN</p>	 <p>BR PETROBRAS</p>
 <p>RSB ROUNDTABLE ON SUSTAINABLE BIOMATERIALS</p>	 <p>SGB™ Seeds Genomics Biofuels</p>	 <p>SINDICOM</p>	 <p>solazyme®</p>	
 <p>USP UNIVERSIDADE DE SÃO PAULO</p>	 <p>WEYERHAEUSER SOLUTIONS EXPERTISE FOR A SUSTAINABLE PLANET</p>		 <p>WWF</p>	 <p>CANTOS DO MUNDO Unidos por um mundo melhor</p>

EDITOR

Luís Augusto Barbosa Cortez

ROADMAP FOR SUSTAINABLE AVIATION BIOFUELS FOR BRAZIL

A Flightpath to Aviation Biofuels in Brazil

an initiative of
BOEING/EMBRAER/UNICAMP and FAPESP

Roadmap for sustainable aviation biofuels for Brazil:
A flightpath to aviation biofuels in Brazil

© 2014

Editora Edgard Blücher Ltda.

Blucher

Rua Pedroso Alvarenga, 1.245, 4º andar
04531-012 – São Paulo – SP – Brasil
Tel.: 55 (11) 3078-5366
contato@blucher.com.br
www.blucher.com.br

Segundo Novo Acordo Ortográfico, conforme 5. ed.
do *Vocabulário Ortográfico da Língua Portuguesa*,
Academia Brasileira de Letras, março de 2009.

É proibida a reprodução total ou parcial por
quaisquer meios, sem autorização escrita da
Editora.

Todos os direitos reservados pela
Editora Edgard Blücher Ltda.

Ficha catalográfica

Roadmap for sustainable aviation biofuels for Brazil:
A flightpath to aviation biofuels in Brazil / Luís
Augusto Barbosa Cortez ...[et al.]; coordenado por
Luís Augusto Barbosa Cortez, Francisco Emílio Baccaro
Nigro. – São Paulo: Blucher, 2014.

Bibliografia
ISBN 978-85-212-0876-1

1. Aviões – Biocombustível – Brasil
2. Aviação – Indústria – Brasil I. Cortez, Luís Augusto
Barbosa II. Nigro, Francisco Emílio Baccaro

14-0702

CDD 665.53825

Índices para catálogo sistemático:
1. Aviões – Biocombustível

The Sustainable Aviation Biofuels for Brazil Project: an initiative of **BOEING/EMBRAER/UNICAMP and FAPESP**

Stakeholders:

AIAB, Amyris, ANAC, Andritz, ANP, APTTA, Bioeca, Byogy, Climate Solutions, CTBE, EMBRAPA Agroenergy, Ergostech, GOL, IAC, APTA, IAE, ICONE, ITA/DCTE, LanzaTech, Life Technologies, Mount Rundle Financial, Neste Oil, NWF, Oleoplan, PETROBRAS, RSB, SG Biofuels, SINDICOM, Solazyme, UNIFEI, USP, Weyerhaeuser Solutions, WWF, 4 CDM.

Research Team and Authors:

1. Luís Augusto Barbosa Cortez, FEAGRI & NIPE/UNICAMP (coordinator)
2. Francisco Emilio Baccaro Nigro, EPUSP/Fuels & Engines and Logistics (co-coordinator)
3. André M. Nassar, ICONE/Land Use & Sustainability
4. Heitor Cantarella, IAC/APTA/Agriculture Sustainability
5. Luiz Augusto Horta Nogueira, UNIFEI/Biofuels Legislation & Policies
6. Márcia Azanha Ferraz Dias de Moraes, ESALQ/USP/Social Aspects & Sustainability
7. Rodrigo Lima Verde Leal, NIPE/UNICAMP/Roadmap Specialist
8. Telma Teixeira Franco, FEQ/UNICAMP/ Refining Technologies
9. Ulf Schuchardt, IQ/UNICAMP/Refining Technologies

Steering Committee Hernán Chaimovich (FAPESP), William Lyons (BOEING), Alexandre Filogonio (EMBRAER)

Executive Committee Carlos Henrique de Brito Cruz (FAPESP), William Lyons (BOEING), Fernando Ranieri (EMBRAER).

Consultants Nirvana Deck (BOEING), Marcelo Gonçalves (EMBRAER), Michael Lakeman (BOEING), Darrin Morgan (BOEING), Luiz Nerosky (EMBRAER), Fabio Santos da Silva (EMBRAER)

Administrative team Fabiana Gama Viana (NIPE/UNICAMP), Workshops Manager; Lilian Andrade (NIPE/UNICAMP), Project Administration Manager; Fernanda Colucci (NIPE/UNICAMP), Support.

Additional Researchers Júlio César Perin de Melo (IQ/UNICAMP), Post-doc; Paula Moura (ICONE), MSc Student; Ricardo Baldassin Junior (FEAGRI/UNICAMP), PhD Student.

Acknowledgements

The Sustainable Aviation Biofuels for Brazil Project would like to thank the cooperation of the following institutions: Escola Superior de Agricultura Luiz de Queiroz – ESALQ/USP, Faculdade de Engenharia Química – FEQ/UNICAMP, Federação das Indústrias de Minas Gerais – FIEMG, Embrapa Agroenergia, Agência Nacional do Petróleo – ANP, Departamento de Ciência e Tecnologia Aeroespacial – DCTA, and Fundação de Amparo à Pesquisa do Estado de São Paulo – FAPESP, which offered their facilities to host the eight workshops organized during the project. In addition, we would like to thank the institutions that helped to promote the workshops: ESALQ-Log, FAPEMIG, and ITA.

Finally, we would like to thank to all participant speakers of the eight Sustainable Aviation Biofuels for Brazil Project Workshops listed below:

Adalberto Febeliano	ABEAR
Adilson Liebsch	Amyris
Al Bryant	BOEING Research & Technology, Brazil
Alexandre Duarte da Silva	ANP
Alexandre Filogonio	EMBRAER
Alísio J. M. Vaz	SINDICOM
Alvaro Prata	MCTI
André José Lepsch	PETROBRAS - TRANSPETRO
Andre Nassar	ICONE
Antonio Maria Bonomi	CTBE
Bernardo Pires	Abiove
Bertil Stromberg	VP Biofuels, Andritz
Bob Bilby	Weyerhaeuser
Carlos Ebner	IATA
Carlos Eduardo de S. Cavalcanti	BNDES
Carlos Henrique de Brito Cruz	FAPESP
Carlos Pacheco	ITA
Celso Lafer	FAPESP
Cristiane Azevedo	4 Cantos do Mundo (4CDM)
Darrin Morgan	BOEING
Dieter Metzner	MDA
Dietmar Schupp	SINDICOM
Donna Hrinak	President of Boeing Brazil
Edegar de Oliveira Rosa	WWF
Eduardo Sanovicz	Associação Brasileira de Empresas Aéreas-ABEAR
Eduardo Soriano Louzada	MCTI
Elimara Assad Sallum	UNICA
Emile van Zyl	Stellenbosch University
Emilio Matsuo	EMBRAER

Fabrcio Brollo Dunham	BNDES
Felix Balaniuc	Instituto Algodão Social
Fernando González Torres	Abengoa
Francisco Emílio Baccaro Nigro	POLI/USP
Gary Garverick	Terrabon
George J. de Moraes Rocha	CTBE
Gerard Ostheimer	USDA
Gerhard Ett	IPT
Glaucia Mendes Souza	USP and BIOEN/FAPESP
Gregory Alan Osadetz	Mount Rundle Financial
Guilherme de Almeida Freire	EMBRAER
Gustavo Paim Valença	FEQ/UNICAMP
Guy de Capdeville	EMBRAPA Agroenergia
Heitor Cantarella	Instituto Agronômico de Campinas (IAC/APTA)
Helder Queiroz	ANP
Jad Finck	Solazyme Brasil
Jader Pires Vieira de Souza	ANP
James Andersen	UOP Renewable Energy and Chemicals
Jan Brockhausen	Nidera
Jared Gonsky	LanzaTech
Jefferson Roberto	PETROBRAS
Jim Kinder	BOEING
John Sheehan	University of Minnesota
Jonathan Posner	US Consulate
José Bressiani	Biograal Investment
José Leonardo de M. Gonçalves	ESALQ/USP
José Vicente Caixeta Filho	ESALQ Dean/USP
Juliano Monteiro Andrade	Transpetro
Julie-Ann Felgar	BOEING Comercial
Júlio Zoé	Instituto Agronômico de Pernambuco (IPA)
Kevin Weiss	Byogy
Liliane Maria Ferrareso Lona	Director FEQ/UNICAMP
Linda Beltz	Weyerhaeuser Solutions
Luciano Libório	SINDICON
Luís Augusto Barbosa Cortez	FAPESP and FEAGRI/UNICAMP
Luis Oriani	Chemtex
Luiz Augusto Horta Nogueira	UNIFEI
Luiz Carlos Estraviz Rodriguez	ESALQ/USP
Luiz Custódio	SIAMIG
Maarten Van Dijk	SKYNRG
Marcelo de Freitas Gonçalves	EMBRAER
Marcelo Saito	National Civil Aviation Agency (ANAC)

Márcia Azanha F. Dias de Moraes	ESALQ/USP
Márcio Nahuz	IPT
Márcio Turra de Ávila	EMBRAPA Soja
Marco Antonio Raupp	Minister of Science, Technology and Innovation of Brazil
Marcos Sawaya Jank	President of UNICA
Marcus D'Elia	ILOS
Maria Auxiliadora Baldanza	COPPE/UFRJ
Mariana Maciel Fonseca	Ministry of External Relations of Brazil
Mario de Carvalho Fontes Neto	Bioeca Brasil
Mateus C. Basilio de Azevedo	Instituto Agronômico do Paraná (IAPAR)
Mauro Berni	NIPE/UNICAMP
Mauro Kern	EMBRAER
Michael Lakeman	BOEING
Nicolas Viart	Bonsucro
Nicole Williamson	LanzaTech
Patrick Mazza	Climate Solutions
Paulo A. Z. Suarez	Universidade de Brasília
Paulo Graziano Magalhães	FEAGRI/UNICAMP and CTBE
Paulo Márcio Siqueira de Aguiar	PETROBRAS
Pedro Arraes	Director-President of Embrapa
Pedro Lacava	ITA
Pedro Scorza	Gol
Pekka Savolainen	Neste Oil
Priscila do Nascimento Costa	Azul
Priscilla Biancarelli Nunes	ESALQ-Log/USP
Raffaella Rossetto	Agência Paulista de Tecnologia do Agronegócio (APTA)
Reynaldo Schumann	Sindicon
Ricardo Rocha	Secretaria de Política Regulatória (SAC)
Richard Adkisson	New Mexico University
Roberto Schaeffer	COPEE/UFRJ
Rodrigo Lima Verde Leal	NIPE/UNICAMP
Rodrigo Rodrigues	Casa Civil da Presidência da República
Rogério Amaury de Medeiros	FINEP
Rosângela Moreira de Araújo	ANP
Ross Macfarlane	Climate Solutions
Rubens Maciel	FEQ/UNICAMP
Sabetai Calderoni	Instituto Brasil Ambiente
Salim Morsy	Bloomberg New Energy Finance
Sébastien Haye	RSB
Segundo Urquiaga	EMBRAPA Agrobiologia
Sergio Beltrão	UBRABIO
Sergio Queiroz	IG/UNICAMP

Simon Uphill-Brown
Telma Franco
Teresa Losada Valle
Ulf Schuchardt
Walter Bartels
Weber A. N. Amaral
William Burnquist
William Lyons

Terrabon
FEQ/UNICAMP
IAC/APTA
IQ/UNICAMP
AIAB
ESALQ/USP
Ceres Sementes do Brasil
BOEING Research & Technology

Foreword

The aviation industry is committed to reducing its environmental impact and has established the ambitious goals to reach carbon neutral growth by 2020 and to reduce carbon dioxide emissions by 50% (from 2005 levels) by 2050. Currently, the aviation industry generates approximately 2% of man-caused carbon dioxide emissions; it is a small but growing share that is projected to reach 3% by 2030.

BOEING and EMBRAER, as leading aviation companies committed to a more sustainable future, have joined efforts to support initiatives to lower greenhouse gas (GHG) emissions derived from air transportation. These emissions represent an important global concern in the 21st century, and the growing aviation industry will need to find ways to reduce its contribution, particularly in substituting fossil fuels by sustainable biofuel.

Airlines are doing their part as well. Globally, they have created the Sustainable Aviation Fuel Users Group (SAFUG), an organization focused on accelerating the development and commercialization of sustainable aviation biofuels and representing about 30% of commercial jet fuel demand.

Brazil is internationally recognized for its long experience of using biomass for energy purposes beginning with wood, sugarcane ethanol, and biodiesel. Modern bioenergy represents around 30% of the Brazilian energy matrix, and has a long track record reconciling biofuel production, food security and rural development. Much of what Brazil has done in the bioenergy area was accomplished by long-term policies and investment in research and by building up human capacity.

In this context, BOEING, EMBRAER and FAPESP initiated this project to conduct a national assessment of the technological, economic and sustainability challenges and opportunities associated with the development and commercialization of sustainable biofuel for aviation in Brazil. UNICAMP was selected for the coordination of this study, with the charter to lead a highly qualified, multi-disciplinary research team. The project team conducted eight workshops with active participation of over 30 Stakeholders encompassing private sector, government institutions, NGOs and academia. The assessment included the most important topics from agriculture, conversion technology, logistics, sustainability, commercialization and policies. The result of this effort is this Flightpath to Aviation Biofuels in Brazil originated from the open dialogue and diverse views of the Stakeholders in a consensous manner. The report lays out the grounds to establish a new biofuels industry to replace jet fuels. In the process, we confirmed that Brazil is a place of great promise to help the world to alleviate fossil fuel dependence in aviation.

The development of a new industry will entail the participation of different sectors of the Brazilian economy including not only research institutions and biofuels producers but also feedstock producers, financial, international relations, academia, the aviation industry, and environmental and social advocacy groups. In developing sustainable aviation biofuels Brazil is seen as a key player, having a unique strategic advantage worldwide.

Donna Hrinak
President of BOEING
Brazil

Mauro Kern
Executive Vice President,
Engineering and
Technology of EMBRAER

Celso Lafer
President of FAPESP

Disclaimer

Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the participating parties. The results, analysis, conclusions or recommendations expressed in this report are based upon consensus from a series of multi-stakeholder workshops, technical presentations, data gathering, benchmarking or otherwise specified assumptions and parameters. To the extent permitted by the law, the participating parties exclude all liability to any party for any loss, expense, damage or cost incurred directly or indirectly from using this report.

Summary

PART I – INTRODUCTION AND CONTEXT, 17

1. INTRODUCTION	19
1.1. Aviation Industry and energy.....	19
1.2. Biofuels and GHG emissions	21
1.3. GHG Emissions and Biofuels in Aviation.....	23
2. GOALS AND DESIRES TO THE NEW AVIATION INDUSTRY	29
2.1. Vision.....	29
2.2. Scope.....	32
3. CURRENT INDUSTRY: PRODUCTS, PROCESSES, SUPPLIERS AND CUSTOMERS	37
3.1. Aviation Fuel Industry in Brazil	37
3.2. The Bioenergy Industry in Brazil.....	39
3.3. Future industry: market trends and projections	42
3.4. Relevant limiters.....	47
Final considerations on TRM process	48

PART II – NEEDS AND TECHNOLOGICAL CAPABILITIES, 51

4. DESIRED PRODUCTS, TECHNOLOGIES OR PROCESSES	53
4.1 Feedstock.....	53
4.1.1 Biomass production	53
4.1.1.1 Feedstock groups	62
4.1.1.2 Sustainability issues	69
4.1.2 Feedstock logistics.....	71
4.2 Refining Technologies	82
4.3 Logistics	84
4.3.1 Actual jet fuel distribution logistics and infrastructure.....	84
4.3.2 Quality assurance procedures for jet fuel.....	88
4.3.3 Requirements for commercialization of alternative jet fuel.....	96
5. CRITICAL SYSTEM REQUIREMENTS	99
5.1 Feedstock.....	99
5.2 Refining Technologies	101
6. LARGE TECHNOLOGICAL AREAS	103
6.1 Feedstock.....	103
6.2 Refining Technologies	103
6.2.1 Pre-treatment processes	103
6.2.2 Conversion Technologies.....	104
6.2.2.1 Gasification	104
6.2.2.2 Fast Pyrolysis.....	104
6.2.2.3 Liquefaction.....	104

6.2.2.4	Hydrolysis	105
6.2.2.5	Fermentation to alcohols	107
6.2.2.6	Lipids from carbohydrates	108
6.2.3	Technologies to produce jet biofuel.....	108
6.2.3.1	HEFA (hydroprocessed esters and fatty acids)	108
6.2.3.2	Alcohol to jet (ATJ).....	109
6.2.3.3	Syngas/Fischer-Tropsch.....	111
6.2.3.4	Direct Sugar to Hydrocarbon (DSHC)	112
6.2.3.5	Catalytic bio-oil upgrading.....	113
6.2.3.6	Hydrogen necessity of different conversion technologies	114
7.	TECHNOLOGY DRIVERS.....	115
7.1	Feedstock.....	115
7.2	Refining Technologies	122
8.	CURRENT SCIENTIFIC AND TECHNOLOGICAL CAPABILITIES	127
8.1	Feedstock.....	127
8.2	Refining Technologies	129
9.	GAPS AND BARRIERS	131
9.1	Feedstock.....	131
9.1.1	Biomass cultivation.....	131
9.1.1.1	Group 1: Sucrose/Starch	133
9.1.1.2	Group 2: Oil bearing feedstock	134
9.1.1.3	Group 3: Lignocellulosic feedstock	136
9.1.1.4	Group 4: Residues or Wastes	137
9.1.2	Feedstock logistics.....	141
9.1.3	Gaps and impacts from sustainability requirements.....	142
9.1.3.1	Sucrose.....	144
9.1.3.1.1	Sustainability gaps.....	144
9.1.3.1.2	Technical Impacts.....	148
9.1.3.1.3	Financial Impacts	150
9.1.3.1.4	Commercial Impacts.....	151
9.1.3.1.5	Sucrose: Summary.....	152
9.1.3.2	Oils	152
9.1.3.2.1	Sustainability gaps.....	152
9.1.3.2.2	Technical Impacts.....	154
9.1.3.2.3	Financial Impacts	155
9.1.3.2.4	Commercial Impacts.....	156
9.1.3.2.5	Oils: Summary	156
9.1.3.3	Lignocellulosics	157
9.1.3.3.1	Sustainability gaps.....	157
9.1.3.3.2	Technical Impacts.....	159
9.1.3.3.3	Financial Impacts	160
9.1.3.3.4	Commercial Impacts.....	161
9.1.3.3.5	Lignocellulosic: Summary	162
9.1.3.4	Wastes	163
9.1.3.4.1	Sustainability gaps.....	163
9.1.3.4.2	Technical Impacts.....	165

9.1.3.4.3 Financial Impacts	166
9.1.3.4.4 Commercial Impacts.....	167
9.1.3.4.5 Wastes: Summary	167
9.1.3.5 Overall view	168
9.1.3.5.1 Final Remarks.....	168
9.2 Refining Technologies	175
9.3 Logistics	178

PART III – TECHNOLOGY DEVELOPMENT STRATEGY, 181

10. TECHNOLOGY ALTERNATIVES.....	183
10.1 Feedstock.....	183
10.2 Refining Technologies	189
10.3 Identified pathways	191
10.3.1 HEFA (Hydroprocessed Esters and Fatty Acids).....	194
10.3.2 ATJ (Alcohol to jet)	195
10.3.3 Syngas/Fischer-Tropsch technologies.....	197
10.3.4 DSHC (Direct fermentation of Sugars to Hydrocarbons).....	198
10.3.5 HDCJ (Hydrotreated Depolymerized Cellulosic to Jet)	199
10.3.6 Final comments on gaps	199

RECOMMENDED TECHNOLOGIES

11. ANALYSIS OF IDENTIFIED PATHWAYS.....	201
---	------------

RECOMMENDED POLICIES

12. INSTITUTIONAL ISSUES ON AVIATION BIOFUELS.....	213
13. R&D PROGRAMS AND COMMERCIALIZATION GAPS.....	217
14. CONCLUSIONS.....	219
REFERENCE.....	227
GLOSSARY.....	239
ANNEX 1 – REGIONALS OUTREACHES.....	251
ANNEX 2 – STAKEHOLDERS COMMENTS	265

