

## ABSTRACT

The Green Airport Concept and the International Flight Academy on Biofuels

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Although aviation plays an indispensable role in today's global economy, it is presently at the center of rising controversy due to its disproportionate contribution to greenhouse gases and the potential to become one of the major causes of anthropogenic climate change. The Baylor Institute for Air Science has been involved in programs aimed at alleviating the environmental impact of aviation. This study identifies ideal conditions for the implementation of a "Green Airport" on the Island of Hispaniola. The island has sufficient natural resources to become energy independent. The implementation of an off-the-grid airport will serve locally as a catalyst to promote energy independence while improving economic conditions; and globally, as a model to be reproduced around the world. This document focuses on the first step of implementation: the world's first flight academy operating solely on biofuels that will provide the foundation to support the establishment of an off-the-grid "Green Airport".

The Green Airport Concept and the International Flight Academy on Biofuels

by

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A Thesis

Approved by the Institute for Air Science

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To Dr. Paul MacCready, who devoted his life to the concept of sustainability. He recognized immediately the potential of the Green Airport concept, enthusiastically endorsed it and continued to encourage this author with:

“Just do it Grazia”!

*“Over billions of years, on a unique sphere, chance has painted a thin covering of life—complex, improbable, wonderful and fragile. Suddenly we humans (a recently arrived species no longer subject to the checks and balances inherent in nature), have grown in population, technology, and intelligence to a position of terrible power:*

*We now wield the paintbrush”*

Paul MacCready

(1925- 2007)

## ABBREVIATIONS

100LL	100 low lead
ACI	Airports Council International
AOPA	Aircraft Owners and Pilots Association
ASTM	American Society for Testing Materials
AVGAS	Aviation Gasoline or 100 Low Lead or 100LL
BEST	Business Excellence Scholarship Team
BIAS	Baylor Institute for Air Science
BIOIDDI	Bioenergy Section of the Instituto Dominicano de Desarrollo Integral
BTU	British Thermal Units
CAA	Clean Air Act
CAAA	Clean Air Act Amendment
CAEP	ICAO's Council's Committee on Aviation Environmental Protection
CAP	Clean Airport Program
CC	Coordinating Commission Team
CCP	Clean Cities Program
CEA	Agriculture and Sugar Council
CH <sub>4</sub>	Methane
CHT	Cylinder Head Temperature
CO	Carbon Monoxide
CO <sub>2</sub>	Carbon Dioxide

CTA	Centro Tecnico Aeroespacial
DNC	Departamento Nacional de Combustíveis
DR	Dominican Republic
E10	10% Ethanol 90% Gasoline
E85	85% Ethanol 10% Gasoline
E95	95% Ethanol 5% Denaturant
EASA	European Aviation Safety Agency
EGT	Exhaust Gas Temperature
EMAS	Eco-Management and Audit Scheme
EPA	Environmental Protection Agency
eq	Equivalent
ETBE	Ethyl-Tertiary-Butyl-Ether
EU	European Union
FAA	Federal Aviation Administration
FARs	Federal Aviation Regulations
ft	Feet
FUNGLODE	Fundacion Global Democracia y Desarrollo
GAIFA	Green Airport International Flight Academy
gal	Gallon
GAMA	General Aviation Manufactures Association
GAW	Global Atmospheric Watch
GCOS	Global Climate Observing System
GHG	Greenhouse Gases

GPH	Gallons Per Hour
H <sub>2</sub> O	Water
Ha	Hectare
HFC	Hydro Fluoro Carbon
HP	Horsepower
IATA	International Air Transport Association
ICAE	International Centre for Aviation and the Environment
ICAO	International Civil Aviation Organization
ICAP	International Clean Airports Program
IDDI	Instituto Dominicano de Desarrollo Integral
IGACO	Integrated Global Atmospheric Chemistry Observations
IGOS	Integrated Global Observing Strategy
INTEC	Instituto Tecnológico de Santo Domingo
IPCC	Intergovernmental Panel on Climate Change
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
ITA	Aeronautical Technological Institute
Km	Kilometer
MAP	Manifold Absolute Pressure
MOU	Memorandum of Understanding
MSL	Mean Sea Level
MW	Megawatts
N <sub>2</sub> O	Nitrous Oxide

NAA	National Aeronautic Association
NASA	National Aeronautics and Space Administration
NGO	Non-Governmental Organization
NO	Nitric Oxide
NO <sub>2</sub>	Nitrogen Dioxide
NO <sub>x</sub>	Nitric Oxide and Nitrogen Dioxide
NREL	National Renewable Energy Laboratory
O <sub>3</sub>	Ozone
PFC	Perfluorocarbon
R	Reals (Brazilian currency)
RAFDC	Renewable Aviation Fuels Development Center
RFA	Renewable Fuels Association
RHP	Rebirth of Hispaniola Project
RPM	Revolutions Per Minute
RVP	Reid Vapor Pressure
SO <sub>x</sub>	Sulphur Oxide
STC	Supplemental Type Certificate
SWRI	Southwest Research Institute
t	Metric Tonnes
TAFC	Texas Alternative Fuel Council
TBO	Time Between Overhaul
TC	Technical Center
TOL	Take Off and Landing

UHC	Unburned Hydrocarbon
US DOE	United States Department of Energy
USDA	U.S. Department of Agriculture
Vol	Volume
Yr	Year

## CHAPTER ONE

### Introduction

The Intergovernmental Panel on Climate Change (IPCC) reports released in February and in May, 2007 (IPCC, 2007) unequivocally assert that global warming is here and is very likely caused by human activity. The scientific data is unambiguous—as stressed by the consensus on the reports reached by governments around the globe and evidenced recently by the award of the prestigious Nobel Prize for Peace to the IPCC panel and to Al Gore (Nobel Foundation, 2007). The Earth is already experiencing global climate change effects from a higher frequency of extreme temperatures and weather events, droughts, fires, floods to rapid melting of glaciers and ice sheets. These phenomena will eventually result in rising sea levels and the demise of entire species causing domino effects in the destabilization of ecosystems and societies and ultimately threatening the very survival of future generations. The IPCC reports stress that humans must urgently make large reductions in greenhouse gas emissions in order to keep the Earth's temperature rise within 2 Celsius degrees and to prevent further drastic and devastating climate changes.

Scientific modeling and predictions concerning the impact of increasing concentrations of greenhouse gases are currently being validated by the observed changes in the environment. These early signs are serious warnings of future potentially catastrophic consequences. Delaying the implementation of measures to prevent further global warming will magnify the environmental impacts and lead to higher costs later to society. The IPCC reports recommend rapidly curbing greenhouse gas emissions while

promoting aggressive research to develop environmentally friendly and sustainable technologies.

The last report (IPCC, 2007) advises governments to set a high price on carbon-dioxide emissions in order to avoid serious consequences by mid-century. It also provides guidelines on ways to reduce emissions through sustainable forest and agricultural land management, improved planning in transportation, the introduction of more fuel efficient vehicles, and the design of more energy efficient buildings. The reports leave no doubt that we are in an environmental emergency.

Concerted efforts of the global community are critical in implementing comprehensive programs to limit the growth of all possible sources of pollution. To date, numerous and often uncoordinated policies have been mandated to regulate conventional air pollutant emissions from industrial and mobile sources of pollution. However, until very recently, none of these regulations have focused on carbon dioxide (CO<sub>2</sub>) emissions.

One major source of conventional air pollutants and CO<sub>2</sub> emissions, which has managed to evade all radar screens and remains unregulated, is aviation.

### *Environmental Impact of Aviation*

Although aviation's environmental impact is not limited to emissions from aircraft, these emissions represent the biggest challenge. There are two major fuels used in today's aircraft: the commonly called "jet fuel" used in commercial turbine engines (called Jet A-1, Jet A, and Jet B) and in military jets (called JP-4, JP-5 and JP-8), and the leaded aviation fuel (Avgas) used in piston engine aviation fleets.

These fuels each have different impacts. The most significant and ubiquitous environmental impact caused by the use of jet fuels is due to the large quantity of fuel



consumed and the altitudes at which commercial airliners and military aircraft operate. In regards to Avgas, while the quantity of fuel consumed is miniscule in comparison to jet fuel, the major problem is that it is the only leaded fuel still in use in the USA. High compression piston engines require a high octane fuel and lead is used to boost octane in Avgas (Chevron , 2000)

The FAA and NASA commissioned a report in 2006 on the impact of aviation on climate change. The report reiterated the conclusions of an earlier IPCC report stating that the impact of aircraft emissions on the climate of our planet might be the most serious environmental issue facing the aviation industry. The report also stressed the urgency of understanding and quantifying the potential impacts of aviation emissions resulting from the anticipated growth in demand in the aviation industry. This type of research would assist policymakers in addressing climate change and other potential environmental impacts (Airports Council International, 2006).

The aviation industry, undoubtedly one of the most vital and essential industries in today's global economy, is a source of rising controversy due to its disproportionate contribution to greenhouse gases and to conventional air pollution. The industry has been prospering in an environmental framework characterized by a general absence of policies limiting its emissions. Considering that aviation is one of the fastest growing industries of the global economy, its largely unregulated emissions have the potential to become one of the major issues of concern of anthropogenic climate change (Pener, Lister, Griggs, Dokken, & McFarland, 1999). The growth of the aviation industry and its contribution to local and global pollution is inconsistent with the principles of environmental sustainability and the urgency to curb emissions.

In the United States there has been a reluctance to even acknowledge the problem much less enact policies aimed at regulating the industry, whereas in the European Union (EU), the issue of emissions from aviation has been at the center of an ongoing debate for the last several years (International Air Transport Association, 2007).

Today, options to address aviation emissions are being considered by governments and aviation and environmental organizations. These options include fuel taxes and charges based on CO<sub>2</sub> loads, voluntary measures enacted by airports or airlines, such as procedures to burn less fuel on the ground, and emissions trading. The fuel consumption efficiency of commercial aircraft engines has improved tremendously in recent years. The next generation of aircraft engines, such as the one utilized in the Boeing 787, which is scheduled to be operational in 2008, will increase fuel efficiency by 15% compared to engines designed a decade ago, increasing to 78 the passenger-miles to the gallon (Dubie, 2007). Technological advances have also greatly reduced the emissions of modern aviation engines with new engines delivering 40% lower emissions than required by current international legislation (International Civil Aviation Organization, 2007).

However, as in the case of the automotive industry, greater reductions in emissions can only be achieved by utilizing cleaner fuels in aviation engines. The same is also true when addressing the other major concern in aviation, the use of Avgas by the general aviation piston engine fleet. Again, Avgas, also called 100 low lead or 100LL, although representing just a small fraction of the gasoline market in this country, is currently the single largest contributor of lead in the atmosphere (Perdue, 2007). At the current consumption level of an estimated 300 million gallons a year (Federal Aviation

Administration, 2005), 0.45 million grams of lead are released yearly into the atmosphere (Nussbaum, 1991). Lead is a confirmed neurotoxin. While the immediate health effects, especially in exposed children, are typically neurological, lead poisoning can affect all major organs in the human body (Department of Health and Human Services, 2007). Research, development and a rapid adoption of cleaner fuels in aviation is an imperative.

### *Research and Development of Alternative Fuels in Aviation*

Notable efforts were made by the governments of Germany and Japan during WWII to produce alternative fuels to power vehicles, including aircraft, for their war efforts. Since then, alternative fuels were mostly ignored until the first oil embargo in 1973 when the realization of the dependence on imported petroleum led to a renewed interest in biofuels (INTUSER).

During the first oil embargo, Dr. Max Shauck, then a National Institute of Health Post-Doctoral Fellow was developing techniques for air pollution research using instrumented aircraft. All of Dr. Shauck's activities at the time involved aviation. Besides flying aircraft to monitor and analyze air pollution, he was a professional air show pilot, unlimited aerobatic competitor, aerobatic instructor, and chief flight instructor for the University of North Carolina's flying club. He became very concerned about an interruption of aviation fuel and began searching for a renewable, domestically produced alternative to aviation gasoline. In the late 1970's, having considered and researched various options, Dr. Shauck started to focus on ethanol as a fuel of choice for piston engines (Shauck & Turner, 1984). Ethanol had the desired characteristics for an aviation fuel.

Dr. Shauck moved to Baylor University in Waco, Texas, in the mid 1970s, accepting a mathematics professorship with a joint appointment at the Environmental Studies Institute. Ethanol was readily available at Baylor University, being produced from waste chocolate by an experimental facility operated by the Baylor Environmental Studies Institute. He flew his first aircraft powered solely by ethanol in 1979. In 1981, he flew his first record flight, an ethanol powered transcontinental flight across the USA. He made other important record flights on ethanol that brought considerable media attention to the topic while he continued to improve and perfect the conversion of aircraft engines to use ethanol.

Dr. Shauck's initial interest in developing an alternative aviation fuel was not inspired by environmental concerns but it was a consequence of the threat to the supply of aviation gasoline (Shauck & Turner, 1984). While the supply of aviation fuel was never curtailed during the oil embargo, dependence on imported oil has increased over the years and the development of a domestic aviation fuel has become a critically important issue. Additionally, environmental concerns and mandates, such as the passage of the Clean Air Act and the phase out of all lead from fuels, provided additional incentives to develop suitable clean burning replacement fuels for aviation gasoline. Recently, the rapid spike in oil prices, and in particular in aviation fuels, is providing further impetus to develop viable cleaner, domestically produced alternatives.

In 1988, a certification proposal was submitted by Dr. Shauck and the author of this document to the Federal Aviation Administration (FAA) to obtain a Supplemental Type Certificate (STC) for an aircraft engine powered by ethanol. The certification of the IO-540 Lycoming series engine on ethanol was obtained in 1990. This certification

was a significant achievement, being the first certification ever awarded by the FAA for an alternative renewable fuel to be used in aircraft engines. (Shauck & Zanin, 1991)

Years of flight testing and demonstrations had proven ethanol to be a high performance, reliable and economically competitive replacement for Avgas. In 1989, Dr. Shauck and the author (co-pilot on the flight) successfully flew an experimental aircraft across the Atlantic on ethanol fuel (Shauck & Zanin, 1991). At the completion of the flight, they founded the Renewable Aviation Fuels Development Center (RAFDC) at the newly formed department of Aviation Sciences at Baylor University, to conduct research and development programs. In 2002, the Aviation Sciences Department and the RAFDC were reorganized under the name of Baylor Institute for Air Sciences (BIAS). Since 1990, several research and development programs have been conducted with the support of the FAA, and numerous educational and demonstration programs were funded by the US Department of Energy (US DOE). In a parallel activity, the certification of engines and airframes on ethanol was supported by state agricultural organizations.

The RAFDC also conducted in the late 1990's an extensive study funded by the Texas Alternative Fuel Council (TAFC) to utilize Biodiesel in turbine engines. A test-stand with a turbine engine provided by the FAA was employed to test various blends of Biodiesel and Jet A-1 fuel while emissions testing of the blends were conducted in parallel. A Beechcraft King Air, with the same engine type as the one tested on the test-stand, was then flown for 60 hours on a blend of Biodiesel and Jet A-1. This program represented the first flight testing of an aircraft on a Biodiesel blend (Shauck & Zanin, 2000).

During the “First International Conference on Alternative Aviation Fuels” held at Baylor University in the fall of 1995, a discussion took place with US DOE officials over the need to create a “Clean Airport Program”. A proposal had been previously presented to the US DOE to establish a program that would integrate the development of alternative fuels for aviation with the use of cleaner alternative fuels for ground transportation and ground support systems at airports. The announcement to establish the program was made during the same conference at Baylor by a US DOE official, appointing RAFDC as the manager of the new program.

### *The Clean Airport Program and Concept*

In May 1996, with the support of the US DOE, the RAFDC at Baylor University launched the U.S. Clean Airports Program (United States Department of Energy, 1996). The Clean Airport Program (CAP) established partnerships between stakeholders, including fixed based operators, local businesses, university aviation programs, flying clubs and local communities committed to solve local transportation and air quality problems by promoting the use of alternative fuels in ground equipment, ground vehicles and general aviation aircraft when possible. Clean Airport partners worked directly with local businesses and governments to create a set of criteria and the process to realize the goals necessary to implement alternative fuels programs and systems at an airport. Five airports in the nation were designated Clean Airports as a result of that program (Zanin & Shauck, 1997).

Due to confusion among federal agencies about jurisdiction for a program that involved aviation, energy and environment, and a political shift in priorities at the federal level, the U.S. Clean Airports Program transitioned into the International Clean Airports

Program (ICAP). The ICAP was developed by a cooperative effort between Baylor University's RAFDC and the International Centre for Aviation and the Environment (ICAE), based in Montreal, Canada.

The international dimension expanded the program's objectives beyond alternative fuels to include energy efficiency, all renewable and alternative forms of energy, and broad-based environmental programs including noise, water, land use, waste minimization and recovery, air pollution and the stabilization of greenhouse gases. The broader approach responded to the needs of a rapidly expanding aviation industry in a world demanding greater environmental responsibility and faced with the need to reduce the use of fossil fuels.

An international airport, the Palm Springs Airport in California, was designated under this program in the spring of 1998. RAFDC carried out all of the preparation work closely coordinating the development with the stakeholders and the management of the airport. RAFDC presided at the designation ceremony together with the local Clean Cities Program and environmental organizations.

This designation received considerable media attention and the ongoing implementation of cleaner and more compatible technologies at the Palm Spring Airport became a success story within the environmental community. However, the ICAP never took off as originally envisioned due to a number of factors. When concerns about aviation's environmental impact first emerged, the government agencies' political unwillingness to deal with the environmental impact of aviation coupled with waning interest in embarking in research to replace low cost fossil fuels prevailed. The aviation industry and community, rather than opting to voluntarily develop a long-term strategy

towards alleviating its impact, has generally chosen to ignore early warnings, continuing for the most part to follow a non-sustainable path. Additionally, the pioneering work and the major accomplishments of this program had been driven by idealism and personal commitments with no funding available.

In recent years, and particularly in these last few months, studies and repeated warnings released by the scientific community of an impending climate change crisis have heightened the awareness of the entire global community to the consequences of environmental degradation. Calls for actions to reduce the environmental impact of modern day practices, to change the established patterns of wasteful resource consumption and resulting pollution, are now being heard, not just from environmental organizations, but from governments as well as major investment and insurance companies all over the globe.

In its position as a leader in technological and economic development, it is clear that aviation has a major role to play in improving the quality of the environment. The upgrading of airports and related infrastructures is vital if any progress is to be made towards the improvement of aviation's environmental record. Several airports and airlines in industrialized countries have recently initiated programs to voluntarily reduce their environmental impact as a result of growing environmental awareness. The recent announcement of Sir Richard Branson joining forces with Boeing to test biofuels in a 747 by 2008 is evidence of the mounting pressures experienced by the industry to adopt environmentally compatible systems—"We all have a responsibility ... to reduce the carbon footprint. Doing nothing should not be an option," Branson said. "The



*environment has become the most important issue facing the world right now.*” (MSNBC News Service, 2007).

Airports and aviation will inevitably be under mounting pressures to adopt environmentally compatible systems. This author never abandoned the idea of creating a model for a sustainable and environmentally friendly airport and has made periodic attempts to interest federal agencies in the establishment of a program with broad implications; a program similar to ICAP, based on a multi-step approach, adaptable by airports according to location, size, current circumstances and future development plans. No federal, state or private organizations in the US showed any interest in the initiative.

The series of efforts initiated by the author and colleagues at the RAFDC, and later the BIAS, to address specific problems related to the environmental impact of aviation provided a considerable wealth of experience on this topic. Other options were explored. A new approach to reconcile modern day society requirements of mobility with environmentally compatible practices inspired the concept of a new “Green Airport” model. This would be designed from scratch rather than struggling to convince stakeholders and their special interests to change established practices. Additionally, instead than just trying to alleviate the environmental impact of existing systems it would have the advantage of focusing on adopting the latest and best renewable energy technologies to provide a model for sustainable and ground-breaking practices.

For this concept to be implemented, an ideal airport site had to be identified to be the model “Green Airport”; a model that could be showcased and reproduced around the world.

### *The Green Airport Model*

The vision of the Green Airport is an integrated approach to create a hub of sustainable practices where research and innovation will be continuously incorporated with ongoing aviation activities such as flight training, aviation and environmental education, recreational flying, eco-tourism and, eventually, scheduled commuter operations.

A conference in the Dominican Republic presented the opportunity to identify an ideal location and ideal conditions for the implementation of the Green Airport model. The Global Foundation for Development and Democracy (Fundacion Global Democracia y Desarrollo - FUNGLODE), a Foundation created by Dr. Leonel Fernandez, current President of the Dominican Republic (DR), organized a conference in November of 2004 to explore and discuss solutions to the numerous environmental and socio-economic problems of the Island of Hispaniola (shared by the two countries of Haiti and the Dominican Republic). Dr. Max Shauck and the author of this document were invited to the conference to present their experiences on the use of alternative fuels in aviation, in particular ethanol, and to take part in the discussion on how to promote the adoption of sustainable forms of energy on Hispaniola. The meeting offered the opportunity to learn more about the environmental, social and political conditions in the two countries. A preliminary evaluation of the natural resources available confirmed that the island had the potential to become energy independent and that it would provide an ideal site to propose the implementation of a Green Airport model. A presentation to explore the interest of the local organizations in the concept was well received. The program was proposed, raising considerable interest among the local government representatives, the aviation

community and environmental organizations. The combination of natural and human resources, the interest and support of the political and entrepreneurial constituencies, combined with the potential to contribute to the development of an energy policy promoting the use of domestically renewable energy sources were the decisive factors in choosing the DR as the site for the development of a Green Airport.

William (Bill) Holmberg, a former US Marine Colonel, has for many decades indefatigably promoted renewable energy and biofuels programs in the United States—and now in the world—and continues unrelentingly to support and to inspire sustainable programs, including the Green Airport concept in the DR. On his first night on the island of Hispaniola, Bill stood on the main square of Santo Domingo, in awe of the Columbus House. During his introduction to a conference on sustainability the next morning he asked his 16 year old granddaughter to read to the audience the following message:

*“I have an unfulfilled dream that was fading until last night when I saw the Columbus building here in Santo Domingo and started reading the book, ‘The World is Flat’, by Thomas Friedman, the famous author and New York Time’s columnist.*

*Friedman brilliantly makes the point that the world has passed through two phases of Globalization. The first started with Christopher Columbus in 1492, when he found that the world was round and could be circumnavigated. He made more common this understanding.*

*During the second phase of globalization, roughly 1800 through 2000, the key agents of change were multinational companies doing business throughout the world with ever increasing means of communications and transport.*

*The third phase started in 2000 with the realization that the computer, the microchip, the internet, fiber-optic cables, and the world-wide web have forever changed the way the world operates. They and the human spirit have “flattened the world” and launched the transformation of economic, political, environmental and religious survival.*

*The world has indeed become flat in terms of opportunities, creativity, competition and collaboration. Race, color and creed (and age – young and old) are no longer principle determinants in judging a person’s value – only ability and character will prevail.*

*Our American continent is unique in its ability to embrace these challenges. We can all call ourselves Americans, although we are proud of our separate nations, just as we in the US are proud of native states. Essentially, only four languages prevail in the Americas—Spanish, English, French and Portuguese. We have a big and protective*

*ocean to the East and to the West. We have friendly nations to the North and the South. We generally have salubrious climates; and, we are blessed with enormous resources, particularly in the area of biomass. Importantly, we will be foolish if we did not look over our shoulder and see the phalanx of scientists and engineers graduating from top notch universities in Asia and other continents. They are the competition of the future.*

*The major challenge of the future is greenhouse gas stabilization, and carbon credits will help finance the needed transformation of Hispaniola. We must dedicate ourselves to the transformation of digging into the earth for carbon energy, and its release of CO<sub>2</sub> to the atmosphere, to the development and use of those resources on the surface of the earth, and in its atmosphere and solar system.*

*We in the Americas can set the pace for this phase of globalization that started just a few years ago -- a phase that brings new importance to the individual. Remember, the first phase was launched here in Hispaniola with Christopher Columbus over 500 years ago.*

*We now have a second chance as citizens of the Americas to embrace life, liberty and the pursuit of happiness—and equality in doing so; and to achieve sustainability in order to protect and preserve God's creation. We have his blessing to succeed. We must not fail” (Holmberg, 2005).*

### *Goals and Objectives*

The goal of this study is to assess the viability of the Green Airport concept, focusing in particular on the development of the first phase of implementation: the Green Airport International Flight Academy (GAIFA) on renewable fuels. The objectives of this study will be: 1. to determine the technical and economical practicality of using biofuels in a flight training fleet; 2. to survey the availability of land in the DR to grow energy crops and their potential to produce biofuels ; 3. to analyze the environmental impact of the GAIFA aircraft fleet including the reduction of emissions and greenhouse gases when comparing it to conventional training operations utilizing fossil fuels; 4. to survey the DR resources and infrastructure that would attract flight students to the GAIFA and to estimate financial advantages for the students; and 5. to evaluate the GAIFA potential contributions to the local community and economy.

Data utilized to conduct this study will include: 1. technical information obtained from past research, development and certification processes conducted on alternative fuels for aviation; 2. ongoing research programs on using ethanol in aircraft and on emissions of ethanol powered engines; 3; results from an ongoing large scale experiment using ethanol powered agricultural spray aircraft in Brazil; 4. personal experience of the author coordinating the US DOE Clean Airport Program (CAP) and the International Clean Airport Program; 5. information obtained during visits to the DR: conferences, discussions and interviews with local personalities, meetings with representatives of foundations, government agencies, university officials and researchers; 6. papers and documents produced by the Re-Birth of Hispaniola Project; 7. use of the world Wide Web.

This document will also support the development of a plan for the implementation of the first phase of the program.

## CHAPTER TWO

### Literature Review

#### *Background on Aviation Emissions and Proposed Legislation*

Commercial aviation is the source of about 13% of transport-derived CO<sub>2</sub> emissions, and it is responsible for around 2.0% of total global anthropogenic CO<sub>2</sub> emissions. Additionally, the latest estimate of total radiative forcing contribution (a measure of change in climate) made by aviation is about 3% of all the human activities (IPCC, 2007).

Turbine engine aircraft emissions are produced as a result of the combustion of jet fuel from the oxidation of carbon, sulphur and hydrogen and the formation of other combustion by-products. The major emissions from aircraft include the greenhouse gases carbon dioxide (CO<sub>2</sub>) and water vapor (H<sub>2</sub>O). Other emissions include nitric oxide (NO) and nitrogen dioxide (NO<sub>2</sub>)—which together are termed NO<sub>x</sub>—sulphur oxides (SO<sub>x</sub>) and soot. These emissions react in the atmosphere to produce secondary pollutants such as tropospheric ozone (O<sub>3</sub>) which is harmful to humans and plants. In the stratosphere, O<sub>3</sub> depletion is extremely harmful since O<sub>3</sub> absorbs ultraviolet radiation from the sun before it strikes the surface (Whitelegg & Cambridge, 2004).

Aircraft emissions of nitrogen oxides (NO<sub>x</sub>), carbon dioxide (CO<sub>2</sub>) and water vapor are largely concentrated in northern latitudes between 30° and 60° north, due to the high frequency of flights at these latitudes; this is an area that includes Europe and North America. There is concern that the rapidly melting polar ice near the North Pole may have been caused by the concentration of airlines flying at these latitudes (Murty, 2002).

About half of all aircraft engine emissions released by the myriad of jet aircraft crisscrossing the globe are emitted in the upper troposphere and lower stratosphere at an altitude of 8-12 Km. At this altitude, the air is highly rarefied since the atmospheric pressure is only a fraction of the atmospheric pressure at sea level and there is much less atmospheric mixing occurring than at lower altitudes. The percentage of greenhouse gases is therefore much higher than at lower altitudes and there is a lower rate of decrease through mixing. Potentially, it is estimated that the impact of all aircraft emissions at an altitude of 8-12 Km is three times more damaging than CO<sub>2</sub> emitted at ground level (Whitelegg & Cambridge, 2004).

Aircraft emissions can cause condensation trails (contrails) which may increase cirrus cloud cover. Water vapor is the most common greenhouse gas and contributes to some 60% of the greenhouse effect. However, water vapor is not regulated by the Kyoto Protocol. The greenhouse gases regulated by the Kyoto Protocol are carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), and nitrous oxide (N<sub>2</sub>O) (United Nations - UNIES, 2007). Other more potent greenhouse gases such as HFCs and PFCs are emitted in relatively small quantities by aircraft.

The impacts of aviation emissions are wide ranging from local (taxi, take-offs and landings in the proximity of airports) to regional (approaching airports or low level flights) and to global levels. While the most damaging effects on climate change are global and occur at the high levels of the atmosphere where emissions are released, local emissions around airports and at lower levels in the atmosphere are also significant.

Aircraft use the most fuel and produce greatest emissions during the take-off and landing (TOL) phases when maximum power is required. As flight distances increase,

the TOL emissions contribution for each flight becomes less significant. Therefore, short-haul flights produce the greatest CO<sub>2</sub> emissions per passenger kilometer (Pener, Lister, Griggs, Dokken, & McFarland, 1999).

The atmospheric lifetime of pollutants varies. CO<sub>2</sub> emissions have a residence time of approximately 100 years. This means that in order to stop the accumulation of CO<sub>2</sub> concentrations and stabilize it at the current level, a 60% decrease in CO<sub>2</sub> emissions is needed (HMSO, 2004). Water vapor's residence time is much shorter, 1-2 weeks. However, the total effects of water vapor, considering the formation of contrails and cirrus clouds, are not completely determined yet, and they may contribute more to localized effects (Pener, Lister, Griggs, Dokken, & McFarland, 1999).

Among the environmental impacts associated with the aviation industry, noise and atmospheric pollution have been receiving the most attention since the publication of the International Civil Aviation Organization (ICAO) Annex 16 of the Chicago Convention in 1969 (International Civil Aviation Organization, 2007). However, recently, the wealth of knowledge on the causes of global climate change has brought focused attention to the full environmental impact of aviation and its broader implications.

This attention is evidenced by the release of the first ICAO Environmental Report in September 2007 (International Civil Aviation Organization, 2007). The report provides comprehensive information assembled by the ICAO Council's Committee on Aviation Environmental Protection (CAEP) and also reports the finding of the latest studies and environmental modeling including the recent IPCC 4th Assessment Report.



The EU Commission, on December 20, 2006, proposed to include aviation in the EU emission trading scheme. The following are excerpts from the “Grounds for and objectives of the EU proposal”: “...*In 2004 greenhouse gas emissions from the Community's share of international aviation increased by a further 7.5% compared with 2003, resulting in a cumulative growth of 87% since 1990. If this continues, there is a risk that growth in the Community's share of international aviation emissions could by 2012 offset more than a quarter of the environmental benefits of the reductions required by the Community's target under the Kyoto Protocol. Since international aviation is not yet covered by the Kyoto Protocol, this growth currently has no legal implications. Nonetheless, this does not lessen its environmental implications which will have to be addressed as part of any effective forward-looking climate policy. The objective of this proposal is to address the growing climate change impact attributable to aviation by including aviation in the Community emissions trading scheme .....*” (European Union, 2006).

The EU proposal envisions the implementation of the scheme in two steps. Starting in 2011, emissions from all domestic and international flights between EU airports will be covered within the scheme. Starting in 2012, emissions from all of the international flights will be covered. The EU intention is to eventually provide this as a model to the rest of world.

The International Air Transport Association (IATA), a global trade organization representing 250 airlines, is not in favor of the initiative and advocates instead that global solutions be implemented through the International Civil Aviation Organization (ICAO).

This suggestion sums up the views of industry players who favor a voluntary approach (International Air Transport Association, 2007).

ICAO, since the early 1980's, has acknowledged environmental concerns and has set standards on aircraft pollution. However, CO<sub>2</sub> and other greenhouse gases were not included since these were considered unavoidable byproducts of jet fuel combustion, and the organization feared that the aviation industry had no alternatives. The ICAO environmental report published in September 2007 still maintains the position against developing guidelines for greenhouse gas emissions fees due to the challenge of reaching consensus among the involved parties. However, it does recognize emission trading as means to address global climate change. ICAO's position on this issue is to suggest numerous conditions for potential charges, including: 1. charges should be directly related to the cost (of mitigating the environmental impact); 2. there should be no taxes, only charges; 3. charges should be transparent (showing all basis for charges); 4. charges should be used for mitigating the environmental impacts; 5. charges should be just (International Civil Aviation Organization, 2007).

The ICAO environmental report acknowledges the seriousness of the IPCC assessments of the potential effects aviation might have on both stratospheric ozone depletion and global climate change. In its closing statements, the ICAO report recognizes the need to pursue concrete measures to reduce aircraft emissions and it suggests, for the first time, the possibility of regulating new engines using alternative fuel sources in the future.

### *Alternative Fuel Research Aimed at Reducing Emissions*

The Renewable Aviation Fuels Development Center (RAFDC) at Baylor University conducted preliminary testing in 1998-1999 to investigate the feasibility of using biofuels as a replacement fuel for the turbine engine fleet. The driving force of the project was the growing awareness of the threat of local and global pollution caused by commercial air traffic.

This author, working as a researcher at the RAFDC, was the principal writer of the proposal to conduct the feasibility study. RAFDC was, at the time, conducting research in air pollution investigations using instrumented aircraft in addition to the development of clean burning renewable aviation fuels. These research areas combine to provide a unique understanding of the urgency and the necessity not only to measure air pollution but also to reduce it by developing cleaner burning fuels.

The Baylor University aircraft (a Beechcraft King Air A90) used for air pollution investigations served as the test flight platform for the alternative fuel blends studied. One of the two engines operated on the alternative fuel, while the other used the conventional turbine fuel. A carefully designed flight test program was conducted. Data were collected and analyzed, and comparisons between the two fuels were made.

The main scope of the program was to test blends of biofuels in the current widely used Jet A-1 fuels in order to reduce the emissions. Blend strengths up to 30% Biodiesel by volume were tested. Several blends were considered and tested for bench properties and for performance in a ground testing facility that included gas emissions instrumentation. One blend was then selected and flight tested (Shauck & Zanin, 1998).

The goals of the program were: 1. to evaluate emission reduction benefits of fuel blends under ambient conditions; 2. to evaluate fuel properties for reducing CO and NO emissions burden; and 3. to compare engine performance and operating efficiency between Biofuels and Jet A-1 fuel.

Results indicated some emissions-reduction benefits in certain blends and under certain ambient conditions (Shauck, Zanin, & Alvarez, 2005). Additionally, cold fuel properties for the blends tested, despite the high freezepoint of neat Biodiesels, were acceptable. They also indicated that Biodiesel blends in turbine fuels may be particularly effective as a means of reducing the CO<sub>2</sub> burden resulting from jet aircraft as well as reducing NO<sub>x</sub> emissions. Preliminary evidence also showed a reduction in particulate emissions, based on observed differences in the soot accumulation on the nacelles downstream of the engine exhaust stacks. This conjecture remains to be explored by further experiments in which particulate emissions of different size are directly measured.

From a performance and fuel economy viewpoint, there was no discernible difference of any kind between straight Jet A-1 operations and operations on Biodiesel blends of 80-20 proportions (20% Biodiesel by volume). Ground and flight test data gathered during the project showed that performance and fuel consumption on the two fuels were comparable (Shauck, Zanin, & Alvarez, 2005).

Biodiesel blends therefore have considerable application as turbine fuel extenders, even if the direct NO<sub>x</sub> emissions benefits never materialize. They have proven suitable as turbine fuels in blends of 20% Biodiesel in flight, and 30% Biodiesel on the ground. In the event that petroleum supplies from the Middle East are disrupted by another

embargo, or a major war, then the existing stocks can be stretched considerably by blending in domestically produced Biodiesels.

Moreover, there is another emissions benefit not directly assessed during this project: the carbon content of a Biodiesel is not fossil carbon. It may be vegetable or animal according to the feedstock of the Biodiesel but it is surface biosphere carbon, not petroleum carbon, and therefore should not count against the global warming carbon emissions limits of the Kyoto Protocol. Routine use of Biodiesel as jet fuel extender could well be the fastest, most effective and most economically viable way to reduce the nation's fossil carbon emissions.

To confirm the conclusions of this study, the first flight on 100% Biodiesel took place in Reno Nevada on October 2nd, 2007. An L-29 military aircraft completed the world's first jet flight powered solely by 100% Biodiesel fuel. The experimental test flights were conducted starting with a blend of jet fuel and Biodiesel. The Biodiesel percentage was gradually increased, eventually resulting in a flight using 100% Biodiesel fuel. Flight tests were conducted up to an altitude of 17,000 feet with close scrutiny of engine data and performance showing no significant difference compared to conventional jet fuel. The aircraft and its crew are preparing for a cross-country flight on 100% Biodiesel, from Nevada to Florida. The aircraft will stop in Waco, Texas, at the BIAS facilities where emission testing will be conducted (Green Flight International and Biodiesel Solutions, 2007).

Jet fuel emissions and related airport traffic and ground equipment pollution, although representing the major aspect of aviation's environmental impact, are not the

only challenge aviation has to face. Another major concern is the use of Avgas (100 low lead or 100LL) in the general aviation piston engine fleet.

### *The Last Leaded Fuel*

The Clean Air Act (CAA) of 1970 gave to the Federal Government authority for the first time to protect human health by cleaning up this nation's air. The new regulations created considerable distress within the petroleum industry which was forced to reformulate gasoline in order to comply. The new mandates created an even greater concern within the aviation industry since Avgas (100 Low Lead) was the only currently available high octane aviation gasoline.

The CAA of 1970 did not live up to its expectations and since its ineffectiveness was further aggravated by increasing fuel consumption, a revision was urged. Consequently, the Congress came up with a massive piece of legislation known as the 1990 Clean Air Act Amendments (CAAA). To complete the successful phase-out of leaded gasoline that had started in the mid-1970s, the CAAA established the ban of fuel containing lead by January 1, 1992, with provisions for annual extensions until December 31, 1995, if adequate alternatives were unavailable.

Due to the difficulties of finding and producing an unleaded alternative to the leaded aviation fuel, the Environmental Protection Agency granted a temporary waiver to Avgas to comply with the ban. As a result of reducing lead in other fuels, Avgas is now the only contributor of lead into the atmosphere from fuels in this country.

Leaded fuels require a dedicated production and transportation system. Besides the unfavorable economic consideration of the production and distribution of this fuel, there are other expenses involved with continued use of leaded fuel. For example, there

are environmental regulations that affect the disposal of the oil used in the engines burning leaded fuel. The oil contains too much lead to be burned in incinerators and must be treated as a toxic waste at a high cost of disposal. Since the aviation fuel market represents a nuisance when compared to the volume of the auto-gasoline market, the petroleum industry will not be able to continue, under these conditions, the production and delivery of such a "small" amount of leaded fuel.

Following passage of the 1990 CAAA, the search for an alternative fuel to aviation gasoline was initiated. The American Society for Testing Materials (ASTM) formed Committee D.2 Section J, and Subcommittee J Section J.2 to consider the problems involved in the development of an alternative fuel for aviation and to examine the proposed alternatives. Envisioning difficulties in producing a high octane unleaded version of the current aviation fuel, the General Aviation Manufacture Association (GAMA), urged the development of guidelines and distributed suggested guidelines to fuel producer organizations. The general description of the fuel characteristics called for a lead -free high octane gasoline suitable for use in power plants approved for LL 100/130 Avgas. The fuel should require only minimum or preferably no engine modifications and minimum impact on operational procedure (General Aviation Manufacturers Association, 1991).

These guidelines were created in an effort to somewhat ease the current requirements for aviation gasolines, some of which were established fifty years ago specifically for large displacement radial engines, most of which are no longer operating. However, these guidelines were developed theoretically and were not tested in the field.

Fuel formulations complying with the GAMA's suggestions were produced in laboratories. Results were presented at ASTM meetings. The Federal Aviation Administration (FAA) Technical center in New Jersey has been testing different types of fuel containing variable concentrations of ethers and other additives intended to improve the octane rating of the fuel (FAA, 2006).

The urgency to find feasible alternatives is dictated also by economic considerations since the requirements to handle leaded fuels have become increasingly restrictive. These factors have already forced an increase in the cost of Avgas. An additional concern is the future availability of some components of gasoline, used in today's Avgas, which will be in higher demand as a result of the implementation of the Clean Air Act mandating the use of reformulated gasoline.

As of today, none of the formulations produced are acceptable when accounting for octane value, environmental impact and cost. There is, however, an existing viable non- petroleum alternative to leaded aviation gasoline. This technically and economically feasible fuel for aviation is 100% denatured ethanol (Shauck & Zanin, 1992).

### *Ethanol in Aviation*

Over the past 27 years, a program at Baylor University in Waco, Texas, has been developing ethanol as an aviation fuel. The project was initiated because of a threat from the federal government to ration the supply of aviation gasoline as a result of the Arab oil embargo of 1973. While supply was never curtailed, US oil imports have increased over the years reaching 70 percent of total consumption in 2007, making the development of an alternative fuel critically important.



The proposed measures provided the motivation to Dr. Max Shauck to search for an alternative fuel. A few years later, in 1979, he was flying his aircraft on pure denatured ethanol. Shauck received backing from Texas oil man and conservationist, Mr. Gus Glasscock, who provided the necessary funds to purchase a Bellanca Decathlon, a two seat aerobatic trainer. The ethanol used in the aircraft for this research was produced in an experimental facility by students of the Environmental Study Institute at Baylor University, headed by Dr. Merle Alexander. The students, lead by Dr. Larry Lehr (then a student) produced the fuel from the waste stream of a chocolate factory, the local M&M Mars production plant.

After a 1981 transcontinental record flight on pure ethanol, Shauck modified and flew two additional aircraft using a 50-50 blend of ethanol and methanol (Shauck, Turner, & Russell, 1986). Flight test data indicated that both alcohol fuels had clear performance advantages over existing aviation fuel. Pursuit of the two necessary steps toward this goal, certification of the fuel with the Federal Aviation Administration and a campaign to educate the public on the advantages of ethanol as an aviation fuel, followed.

In 1987, after an initial failed attempt to complete the first alcohol fueled transatlantic flight, the Italian company "Ferruzzi" offered to sponsor a transatlantic flight on ethanol. Shauck was asked to fly air shows in Italy with his ethanol powered Pitts Special while modifying an Italian built aircraft, a SIAI-Marchetti SF260 (Shauck M. E., 1988). In Italy, Shauck met the author, an Italian pilot and flight instructor, and they decided to make a second attempt at a transatlantic ethanol-fueled crossing together.

The sponsorship of the Italian company fell through due to the decision of the European Community to postpone a vote to use surplus grains to produce ethanol in

Europe. Dr. Shauck and the author decided to proceed without sponsorship and modified an experimental aircraft, a Velocity, to be used for this flight. After many delays, due to bad weather and aircraft instrumentation problems, the flight was completed in December of 1989. This was the first transatlantic flight made on a non-petroleum fuel.

Meanwhile, FAA certification was in progress on a Lycoming IO-540 aircraft engine to use ethanol. The certification was successfully completed the following year. This represented the first certification by the FAA of an entire series of aircraft engines on a non-petroleum fuel. In 1993, another series of aircraft engines used in the most common aircraft trainers, the Lycoming O-235, received certification on ethanol. (Shauck & Zanin, 2003)

The research effort, formally organized at Baylor University as the RAFDC, developed test programs for ethanol, ethanol/methanol, and various blends of those fuels. RAFDC has also evaluated and tested ethyl-tertiary-butyl-ether (ETBE) as a fuel for aviation (Shauck & Zanin, 1996) (Shauck, Zanin, & Johnson, 1998). Using 100% ETBE, a Pitts Special S2B aerobatic aircraft performed at the world's largest show, the Paris Airshow in France, in 1995. This aircraft is still employed in research programs and demonstrations and alternatively uses Avgas, ethanol or ETBE. Many years of testing, cross country flights and demonstrations have provided evidence that ethanol is the best candidate to replace Avgas, as a high performance, reliable and cost competitive aviation fuel.

RAFDC has received several grants and contracts from the US DOE to conduct demonstration flights all around the US. The State of Texas has funded the certification of the Lycoming O-235, and the FAA has been funding research to improve efficiencies

and emissions of aircraft engines fueled by ethanol. Additionally, a number of state agricultural organizations supported the certification of an ethanol powered Piper Pawnee (Shauck & Zanin, 1994).

Ethanol, or ethyl alcohol, is a renewable fuel produced from feedstocks containing starch or sugar. In the United States, ethanol is made mainly from corn and other types of grain or, in smaller quantities, from waste products. In South America ethanol is made from sugar cane, while in Europe it is produced mainly from sugar beets and from agricultural surpluses. Ethanol can also be made from cellulosic biomass and various types of waste products (National Renewable Energy Laboratory, 2007).

The current production of ethanol in the U.S. is approximately 6 billion gallons a year (Renewable Fuels Association, 2007). Most of this ethanol is used as an octane enhancer, blended with gasoline at 10% and, to a lesser extent, in an 85% blend available at selected locations all around the country. Ethanol used as an oxygenate improves combustion reducing CO emissions and also some of the emissions which contribute to ozone formation. While providing octane, ethanol reduces or replaces other environmentally harmful components in gasoline such as benzene, toluene, and xylene—since ethanol does not contain aromatics. These substances are known human carcinogens.

The fuel currently used in the research and development program at Baylor University is 200 proof denatured ethanol. Modifications of engines and airframes to utilize ethanol have undergone continuous improvement and have proven successful and reliable in engine certification tests designed and monitored by the Federal Aviation Administration (FAA). Throughout the course of the research, development, flight

testing, and certification, ethanol has proven to be a high performance, and economically competitive replacement for 100 octane aviation gasoline.

Several aircraft modified by Dr. Shauck to run on pure ethanol have logged over 6,000 hours of flight time during testing, cross country flights and demonstrations (World Biofuels Symposium - China, 2006). To prove the reliability of ethanol as a fuel for aviation, a number of long distance flights resulting in National Aeronautic Association records were completed (National Aeronautic Association, 2007). Ethanol powered aircraft have flown aerobatic demonstrations at major shows in the United States, Brazil, Australia, Italy and France.

Certification is necessary for an aircraft to engage in commercial operations. Dr. Shauck and the author received the first non-petroleum certification for an aircraft/engine combination from the FAA (Shauck & Zanin, 1991). Two series of aircraft engines and two airframes have received FAA supplemental type certificates (STC). These engines and airframes were carefully selected in order to rapidly spread the use of ethanol in the general aviation market. Two areas of aviations were initially identified by Dr. Shauck and this author: the flight training market and the agricultural flying market. In both cases the activities depend almost entirely on centralized fueling facilities thereby avoiding an initial distribution problem.

The aviation gasoline market represents an ideal niche for pure ethanol fuel (called E95 since it contains up to 5% denaturant). At today's prices, ethanol (\$ 2.00-2.50 per gallon) is already economically competitive with Avgas (\$ 4.00 – 5.00 per gallon). In the future, the economic advantage of ethanol over Avgas can only increase: the price of ethanol is more likely to decrease as new production technologies develop

and feedstock bases are expanding, while the price of Avgas can only increase in the future.

The size of the Avgas market is ideal when related to the current production of ethanol in this country, particularly considering the significant expansion of the ethanol industry that guarantees the availability of ethanol for this market.

Beside its economic advantage and superior performance, the adoption of ethanol as an aviation fuel will have many positive impacts in creating rural employment, increasing use of agricultural crops or woody biomass crops, reducing dependence on imported, non-renewable petroleum products, reducing emissions from internal combustion engines, and reducing federal crop subsidies.

Ethanol is a high octane fuel which does not require any additives to perform in existing aircraft engines. It has been proven superior to aviation gasoline in almost every aspect of performance. Ethanol produces more power, extends engine life and has a lower cost per mile. The only drawback is a reduction in range. Given the current dependence from imported petroleum, the increasing cost of fuel and the fact that lead must be removed from aviation gasoline, the arguments in favor of ethanol are very strong.

#### *Certification of the First Training Aircraft on Ethanol Fuel*

In order to be used in commercial operations aircraft must be certified by the FAA. In order to certify a new fuel, both engine and airframe must satisfy FAA requirements.

The use of ethanol in flight training operations offered the best arena to demonstrate the reliability and high performance of ethanol as an aviation fuel and to

establish its economic viability while avoiding distribution problems. Accordingly, the Cessna 152, the most common flight trainer, was chosen to be certified.

This aircraft is powered by a carbureted Lycoming engine, the O-235. This engine was modified for using ethanol and a test plan for certification was submitted to the FAA. After extensive testing, the certification of the O-235 was awarded by the FAA in November of 1993. The FAA certification of the engine-airframe combination for the Cessna 152 to use ethanol was obtained in May 1996.

### *Ethanol Performance*

Ethanol is a high octane fuel which does not require any additives to perform in existing aircraft engines. The most critical factor from the pilot's perspective is the ability of a fuel to produce power. Ethanol produces more power than Avgas because ethanol has a higher latent heat of vaporization. Therefore, under the same atmospheric conditions ethanol will have a higher charge density than gasoline. In the case of the Cessna 152 engine, the Lycoming O-235, dynamometer tests during the FAA certification showed that it produced 20% more power on ethanol than on Avgas. The improved performance is a considerable safety advantage, especially for aircraft operating at high altitudes and/or high temperatures.

Ethanol burns cooler and cleaner and has a lower Vapor Pressure when compared to Avgas, thereby lessening the likelihood of vapor lock. The only drawback of ethanol is a reduction in range, the magnitude of which is directly related to the compression ratio of the engine.

The lower energy density and lower Vapor Pressure of ethanol compared to Avgas, require some modifications to the engine and the airframe. It is necessary to

modify the carburetor to allow for a higher flow rate. The higher flow rate requires the installation of an engine driven pump and an emergency boost pump. When operated on Avgas, the Cessna 152 does not require these pumps, because of the lower fuel rate.

The lower Vapor Pressure of ethanol causes difficulty in starting in temperatures below 65° F. A small canister containing Avgas is installed on the firewall and in cold weather the engine is primed with a small amount of Avgas to start it. Additionally, because of the increased flow rate, an electronic fuel flow indicator with a totalizer is installed as a safeguard against running out of fuel.

During the engine certification of the Lycoming O-235 engine on ethanol, it was determined that the engine developed 126 HP and required 12.9 gallons of ethanol per hour (GPH). Since a 5% increase in HP is the maximum allowable by the Federal Air Regulations, the engine installation has to be limited to 113 HP as the rated HP of this engine is 108 ( $108 \times 1.05 = 113$ ). In order to be conservative, for the design of the fuel system test, a power rating of 126 HP was used to establish the fuel flow rates. Using these criteria, it was determined that the minimum required fuel flow was 16.2 GPH. The engine driven pump delivered a flow of 30.5 GPH and the emergency fuel pump delivered 22.08 GPH. Thus, both pumps exceeded the test requirements by a substantial amount (Shauck & Zanin, 1997).

The Cessna 152 aircraft has been flying on ethanol since the FAA certification was granted. It was displayed at air shows around the USA. It performed excellently at high altitudes, such as through a mountain pass in Colorado on its way to Idaho, and at high ambient temperatures. Data has been recorded and analyzed during cross country and local flights (FAA Contract number TFA03-01-C-00022).

### *Materials Compatibility*

The issue of materials compatibility, caused by the interaction between ethanol and aluminum, was resolved by allodizing all fuel wetted aluminum parts. However, the ethanol industry, experiencing the same problem with its storage tanks, began adding an anti-oxidant to the ethanol. This additive prevents the reaction between ethanol and aluminum. However, for added protection, allodization of aluminum parts is still recommended.

To ensure that there are no other materials compatibility problems, a number of soak tests of elastomers and metallic components were conducted during the certification process. In addition, Southwest Research Institute (SWRI) of San Antonio performed materials compatibility, luminosity and lubricity tests on denatured ethanol, a 50/50 blend of ethanol and methanol, and Avgas and compared the results. This extensive testing on denatured ethanol showed no adverse effects on any materials, other than aluminum, acceptable luminosity characteristics, and slightly better lubricity properties than Avgas. It should be pointed out that the difference between the lubricity of ethanol and Avgas was so slight as to fall in the range of experimental error; consequently, we assume the lubricity of denatured ethanol and Avgas to be about the same.

The lubricity test results were a surprise, as even ethanol proponents believed that it would be necessary to add a top lubricant when using ethanol as a neat fuel. The results of all these tests were corroborated during the 150 hour engine test stand certification of the IO-540. On all measured components (as part of the procedure certain components are measured before and after the test), equal or less wear was measured than is usually detected during similar tests on Avgas (Russell, 1989). This was most likely



due to a combination of smoother operating characteristics, adequate lubricity, cooler operating temperatures and less internal combustion byproduct buildups.

The certification of the Cessna 152 aircraft confirmed the viability of ethanol as an aviation fuel. All of the initial technical problems have been solved. Performance is enhanced in all aspects while the only drawback, range loss, can be considerably reduced by further modifications to the engine. The phase-out of low lead aviation gasoline is impending. Ethanol can be the alternative.

The Cessna 152, the most economical trainer in the world, now certified to use ethanol fuel, has been chosen to be the initial flight training aircraft at the Green Airport International Flight Training Academy (GAIFA). Five of these aircraft are in the process of being prepared to be flown to the Dominican Republic. The GAIFA will be the first flight training operation on biofuels.

#### *Emission Testing of Ethanol in Aircraft Engines*

Although the search for an alternative fuel was initially motivated by a threat of supply interruption, it is now motivated by environmental imperatives and economics. The need to replace lead in gasoline, to provide oxygen to lower carbon monoxide levels, to reduce carcinogens or highly photochemically reactive aromatic hydrocarbons and to reduce the quantity of CO<sub>2</sub> in the atmosphere are major incentives to develop and adopt cleaner fuels in aviation.

Considering the current environmental pressures, a reduction in emissions is going to be a critical factor in the acceptance of the new aviation fuel. The Environmental Protection Agency (EPA) has in the past considered imposing restrictions on general aviation in some of California's metropolitan areas. EPA studies have

determined that aviation represents a significant source of air pollution in these areas.

Reduction in the number of hours flown and/or operations fee programs were proposed as a measure to reduce emissions (California EPA - Resources Board, 1994).

One of the major advantages of ethanol over gasoline is less polluting emissions. Emissions testing of ethanol powered engines have been conducted at BIAS for the last decade. An emission testing program conducted in the 1990s, under a FAA program, compared emissions of ethanol with those of aviation gasoline in a Lycoming IO-360 aircraft engine. Ethanol emissions of hydrocarbons measured less than 50% of those on Avgas. Emissions of CO<sub>2</sub> for Avgas and ethanol showed very close levels (the net CO<sub>2</sub> balance for ethanol versus Avgas is discussed in a separate section below). Ethanol emissions of NO<sub>x</sub> showed an increase under certain conditions when compared to Avgas. However, these measurements were inconclusive. Carbon monoxide levels in Avgas emissions measured 40% greater than those of ethanol. All of these comparisons were made at full power and full rich mixture settings. These emissions tests were conducted with limited emission equipment instrumentation and therefore this data set was incomplete. BIAS is currently conducting a new round of emission testing under a program funded by the FAA to reduce emissions of ethanol utilizing a catalytic converter (FAA Grant number 02-G-035). Recent results of the testing will be reported in chapter four.

#### *Green House Gases (GHG) Emission Reductions*

The reason to treat the GHG emissions reduction under a separate heading is due to the complexity involved in analyzing this issue. As mentioned above, ethanol CO<sub>2</sub> emissions measured during the FAA testing were very close to those of Avgas. However,

when calculating CO<sub>2</sub> emission reduction, the CO<sub>2</sub> life-cycle involved in the production of the feedstock and of the ethanol has to be considered.

Any fuel combustion releases CO<sub>2</sub>. In the case of fossil fuels it is carbon removed by plants from the atmosphere billions of years ago and stored underground or under water. Ethanol's combustion also releases CO<sub>2</sub> but bioenergy crops are able to offset CO<sub>2</sub> emissions by converting inorganic carbon into organic carbon in biomass and soil. On the other hand, the production of biofuels requires fossil fuels while the chemicals added and agricultural processes also release GHG, the primary sources of these being soil nitrous oxide emissions and the CO<sub>2</sub> emissions from farm equipment.

Ethanol production and combustion recycles a share of CO<sub>2</sub>, although the amount of the CO<sub>2</sub> recycled depends on a large number of factors, among which is the use of fossil fuels during the growing and the fuel production process.

Several studies (Shapouri, Duffield, & Wang, 2002) (Pimentel, 2003) (Adler, Del Grosso, & Parton, 2007) (Wang, Wu, & Huo, 2007) have analyzed the energy balance of ethanol production (total energy input to produce the fuel versus energy contained in the fuel) that use a wide variety of assumptions and therefore reach different and often contradictory conclusions.

The calculations, for example, of the energy balance of ethanol produced from corn include not just the energy required to convert the corn into ethanol, but also energy inputs derived from farming and transportation, distribution of the fuel and energy credits resulting from co-products. The results of these studies depend heavily on the number of factors introduced in the model. The magnitude of CO<sub>2</sub> reduction indicated by the respective studies will consequently depend on the system boundary choices considered

by the particular author. These choices can be grouped into operation-related activities that would include emissions resulting from the use of fertilizer, nitrogen fertilizer and lime, farming and transportation in the field, production and transportation of ethanol and energy used for producing and processing the fuel; and boundary activities that could include materials used in the construction of ethanol plant, food and energy used by farmers, materials and manufacture of the farming equipment and solar energy embedded in biomass (Shapouri, Duffield, & Wang, 2002).

Due to the range of factors introduced in these studies, the results are as varied as their authors. Results have ranged from calculated energy losses of approximately -30% to energy gains of approximately +30%. The major differences among these studies are the assumptions made on what to include in the boundary activities (secondary energy inputs); in simple words, where to draw the line around the model considered.

A 2002 study published by the U.S. Department of Agriculture (USDA) analyzed the differing factors between the studies, compared the differences and updated a previous study on the energy balance of corn ethanol. The authors of this study (Shapouri, Duffield, & Wang, 2002) concluded that there is a net +34% energy balance for corn ethanol. On the other hand, one of the most controversial studies on energy balance of corn ethanol, by David Pimentel, a professor at Cornell University, (Pimentel, 2003) still argues that the energy balance for corn ethanol is negative, about -29%.

During a presentation made at the Johns Hopkins Physics Laboratory in December 2006, Pimentel's factors were challenged by a number of scientists who argued that the data used in the study were obsolete and did not take into account the progress made in the last years in all sectors involving the production of ethanol, from

agriculture advancements in growing the crops to the greater efficiency of new generation ethanol plants and the additional energy input of the co-products. The studies conducted by Shapouri and Wang, on the other hand, are updated on a regular basis to consider all of the ongoing technological advances in this field.

The calculations of both energy balance and CO<sub>2</sub> emission reductions differ greatly according to the type of feedstock used to produce ethanol and the extent of fossil fuels utilization during the various phases of the process, from planting to fuel production. If, for example, ethanol production involved no fossil fuel inputs, we could conclude that the resulting fuel would be carbon neutral: what was produced during combustion was taken up during the growth cycle. This ideal situation might be realized in the future.

In most recent studies, GHG emissions of CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O are referred as CO<sub>2</sub>-equivalent and are weighted according to their global warming potentials (1 for CO<sub>2</sub>, 23 for CH<sub>4</sub>, and 296 for N<sub>2</sub>O). In one of these studies (Wang, Wu, & Huo, 2007), 12 different scenarios of ethanol production are presented together with the effects on GHG emissions relative to the results for future gasoline emissions. Using all of the different options currently available as fuels to provide the energy for the ethanol plants, from coal to biomass, a range of GHG emission reduction is obtained. The study shows that the variation ranges from a 3% increase in GHG when coal is used as process fuel to a 52% reduction when biomass is used. The study concludes that on average, emissions can be reduced by 19% in 2007 and by 21% in 2010. The study also underlines that cellulosic ethanol, produced from switch grass for example, is the best option to reduce emissions achieving an 86% reduction in GHG.

Another analysis by a team of researchers at the University of California at Berkeley concludes that a transition from gasoline to ethanol could have an “ambiguous effect” on greenhouse gases (Plevin, Turner, Jones, O'Hare, & Kammen, 2006). The study reports a range of values from a 32% decrease to a 20% increase and concludes that a 13-percent reduction of GHG is likely to occur with ethanol.

Researchers at Colorado State University, in collaboration with the U.S. Department of Agriculture, have completed another analysis of GHG emissions from biofuel production. Their results report that ethanol from corn reduced GHG emission by nearly 40 percent when compared with the life cycle of gasoline and diesel. Ethanol from switch grass would reduce emissions by 115 percent (Adler, Del Grosso, & Parton, 2007).

The conversion of sugar cane to ethanol benefits from a much higher energy gain than corn ethanol since sugar cane provides its own renewable fuel for the conversion processes. Distilling ethanol from sugar cane produces bagasse, which is burned to generate the energy needed in the production process leaving a 12% surplus bagasse that can produce extra power to be sold to other industries. Sugar cane is composed of 1/3 sucrose, 1/3 bagasse and 1/3 dry matter with only sucrose being fully used to produce the ethanol. Through a number of studies, conducted since 1985 and revised every few years to account for improved productivity, the favorable energy balance of Brazilian ethanol has been determined to be around 8.3 (for each fossil fuel energy unit input, 8.3 renewable energy units are obtained) (Macedo, Leal, & da Silva, 2004).

As in the case of the analyses conducted for corn ethanol, the energy input in the analyses of sugar cane energy balance included the direct energy spent in fuels and

electricity, the energy spent in the production of chemicals and materials used in the agricultural and industrial processes, and the energy used in manufacturing maintenance equipment and buildings.

The same inputs are considered for the analyses of the reduction in life cycle GHG emissions. The latest study conducted in Brazil (Macedo, Leal, & da Silva, 2004) to determine the GHG emissions derived for sugar cane ethanol accounts also for the recent restrictions to burning sugar cane and the increased mechanization in the harvesting. The study considers the production of both fuels, hydrous and anhydrous ethanol, since both are commercially used in Brazil. Following are the results of this analysis:

Emissions for Hydrous Ethanol (t CO<sub>2</sub> eq / m<sup>3</sup>)

Year	2005
Fossil fuels	0.19
Trash burning	0.10
N <sub>2</sub> O from soil	0.07
Total	0.36

*\*Hydrous ethanol, the product of the distillation process, contains 5% water. In Brazil it is commercially used in dedicated hydrous ethanol vehicles or in flexible fuel vehicles.*

Emissions for Anhydrous Ethanol (t CO<sub>2</sub> eq / m<sup>3</sup>)

Year	2005
Fossil fuels	0.20
Trash burning	0.10
N <sub>2</sub> O from soil	0.07
Total	0.38

*\*Anhydrous ethanol is nearly 100% pure (trace amounts of water) and can therefore be blended with gasoline. In Brazil it is blended at about a 20-25% level in gasoline. In other countries, as in the USA, it is mainly used in a 10 % blend with gasoline.*

The avoided emissions (converted to t of CO<sub>2</sub> equivalent/m<sup>3</sup> ethanol) were calculated to be 2.86 and 2.16 t CO<sub>2</sub> eq. / m<sup>3</sup> ethanol, anhydrous and hydrous respectively, considering conditions in the Center-South part of the country as reported in Table 1 (Macedo, Leal, & da Silva, 2004). This calculation used the equivalencies between the renewable fuel (ethanol, bagasse and electricity) and the fossil fuels replaced, accounting for their respective life cycle emissions.

Table 1. Avoided emissions (t CO<sub>2</sub> eq / m<sup>3</sup> ethanol hydrous or anhydrous)

Ethanol	Hydrous	Anhydrous
Surplus biomass	0.08	0.08
Surplus electricity	0.02	0.02
Use of ethanol	2.07	2.76
Avoided emissions	2.16	2.86

Table Adapted from MACEDO et al. (2004).

Macedo et al. calculated that the manufacturing of anhydrous ethanol produces about 3 to 4% higher emissions compared to hydrous ethanol, mostly due to the drying process. However, the authors considered for their energy equivalence conversion the fact that most applications in the world will use anhydrous ethanol as a blend of up to 10% (vol) with gasoline, therefore they applied an equivalence of 1 liter ethanol = 1 liter gasoline for anhydrous ethanol and an equivalence of 1 liter ethanol = 0.75 liters gasoline for hydrous ethanol used in dedicated ethanol engines.

The climatic conditions in the Dominican Republic, the base of the Green Airport, are similar to the conditions in Central Brazil. The new technologies that are being implemented on the island will also bring improved productivity in the field and in the



mills, so that the figures from this Brazilian study will soon apply to the sugar cane ethanol produced in the DR (Bros, 2005, Personal Communication).

### *The Brazilian Experience*

Since the GAIFA will be the first commercial flight training operation in the world to utilize ethanol, it is important to report on the technical and economic aspects and results of an ongoing full-scale experiment being carried out in Brazil. The cultivation of sugar cane and the production of sugar and ethanol in Brazil are responsible for considerably improving living conditions in rural areas, generating jobs and increasing family incomes. The agricultural activity alone assures jobs to more than a million workers while it has been estimated that the ethanol producing sector employs directly and indirectly around three million workers. Over the period 1975 to 2002 the Brazilian “Proalcool” program substituted 54.76 billion gallons of fuel ethanol for gasoline. The value at world market prices saved Brazil 52.1 billion US dollars (Plinio, 2003). In the last 20 years, Brazil has developed an ethanol distribution infrastructure in all 25 thousand fuel stations, efficiently covering all of Brazil to ensure regular supply of 3 million vehicles. The introduction of flexible fuel vehicles in 2002 considerably increased ethanol consumption in Brazil, prompting an agreement between the Federal Government and the ethanol producers to increase the production for the 2003/2004 harvest by 1.5 billion of liters that translated in a 13% increase in the total production of fuel ethanol. The growth of production also stimulated the export of fuel ethanol to other countries in the world. In order to avoid domestic market shortages of ethanol, the producers of the sugar cane in the states of São Paulo, Paraná, Mato Grosso, South Mato Grosso, Goiás, Rio de Janeiro and Espírito Santo established mutual agreements and

agreements with the Government to institute a self management system to monitor the production of ethanol fuel in order to keep the domestic market supplied, and to avoid the problems experienced in the 1990s when shortages of ethanol in the domestic market severely reduced the sale of 100% ethanol powered cars and nearly brought the Proalcool program to an end.

The flexible fuel cars introduced in the Brazilian market can function on any blends of ethanol and gasoline. Ethanol in Brazil is readily available nationwide either as a neat hydrous ethanol, containing 5-7% water, to be used in dedicated vehicles and flexible fuel cars, or as anhydrous ethanol that is blended at a 20-25% in all gasoline to be used in conventional vehicles. The current fuel ethanol production in Brazil is approximately 16.5 billion liters per year (Hearn, 2007). These market conditions established the basis for the implementation of ethanol as an aviation fuel in Brazil.

The work of Dr. Max Shauck, who had pioneered the use of ethanol as an aviation fuel, has shown the feasibility of both fuels, hydrous and anhydrous ethanol, as excellent fuels for aviation piston engines. As a matter of fact, the initial testing of ethanol as an aviation fuel was accomplished on hydrous ethanol produced in the experimental facility of the Environmental Study Institute at Baylor University. Further developments in the USA concentrated on the use of anhydrous ethanol, the main reason being its widespread use in a 10% blend in gasoline. The economics of ethanol production in Brazil coupled with a spike in aviation fuel costs have recently sparked a sudden interest in ethanol as an aviation fuel.

*Background: Ethanol as an Aviation Fuel in Brazil*

In 1983, Dr. Lamartine Navarro, one of the Brazilian initiators of the Proalcool Program, invited Dr. Max Shauck of Baylor University to visit Brazil and to hold a series of formal and informal discussions concerning the possibility of cooperation in the development of ethanol as an aviation fuel in Brazil. Over the intervening years, Dr. Shauck, Dr. Navarro and one of his associates at the time, Dr. Plinio Nastari met numerous times to discuss the potential of the program in Brazil. Dr. Navarro purchased the first aircraft ever modified to run on ethanol by Dr. Shauck and together with his pilots flew it to Brazil. In 1988, Dr. Shauck and the author of this document visited Brazil and conducted a number of workshops and flight demonstrations with the ethanol powered aircraft bought by Dr. Navarro. There had been a few earlier attempts to research and implement ethanol as an aviation fuel in Brazil. In the early 1980s, the CTA, the Aerospace Technological Center, in São Jose dos Campos, São Paulo, converted a Lycoming IO-540 engine to run on ethanol, on a Neiva Universal T25 aircraft (of the Brazilian Air Force). The aircraft never flew on ethanol and a process to obtain a supplemental type certification was never initiated. The program was abandoned due to lack of resources, infrastructure, and official interest. During the same decade, at the Aeronautical Technological Institute (ITA), in São Jose dos Campos, Engineer Dawilson Lucato also experimented with ethanol fuel. However, due to lack of funds and interest, he did not pursue this research either (Zanin & Shauck, 2004).

In the meantime, in the US, a certification process was initiated by Dr. Shauck and this author with the FAA to obtain a Supplemental Type Certificate (STC) on a Lycoming IO-540 engine to use E-95 (denatured ethanol). Once the aircraft engine

certification was obtained, an airframe certification process (engine/airframe combination) was completed, in April of 2000, for an agricultural spray aircraft called Piper Pawnee to utilize ethanol. This aircraft is a very popular agricultural aircraft commonly used in many countries around the world including Brazil, where it is used to spray the sugar cane.

During these years, the cost of aviation gasoline in Brazil increased while the cost of ethanol decreased. When the costs of aviation gasoline reached levels of approximately two to four times or more the cost of ethanol, according to states and transportation costs, ethanol as an aviation fuel started to make great sense. Economics provided a strong incentive to accelerate the introduction of ethanol as an aviation fuel in Brazil.

In November of 2001, Tangará Aeroagrícola in Orlândia, in the State of Sao Paulo, converted a Piper Pawnee aircraft to ethanol using Dr. Shauck's technology. The aircraft flew successfully on ethanol. The experiment that year was limited to field tests. However, during the 2001/2002 harvesting season, Tangará Aeroagrícola pioneered the first Piper Pawnee flying on ethanol in Brazil. The Piper Pawnee was the aircraft that better suited the crop dusting activities of the company in the West of São Paulo and in Minas Gerais "Triângulo" areas. During the 2002/2003 harvest, three more ethanol powered Piper Pawnees flew a total of 1,500 hours.

For the past 5 years, Dr. Shauck and the author have been helping Tangará Aeroagrícola implement the conversion of aircraft to ethanol fuel. The process of validating in Brazil the FAA STC for the Piper was initiated with the Brazilian Aviation authorities in early 2003.

The program attracted immediate attention given the level of development on ethanol as a ground transportation fuel in Brazil and the distinctive research and experience of Dr. Shauck in the United States on the use of this fuel in aviation. The technical advantages and economic benefits experienced in the field by the pilots of the first generation of modified Piper Pawnees soon became widespread knowledge in the agriculture aviation sector. These pilots were asked to describe the differences they experienced on an operational level. They listed the following:

#### *Technical Advantages*

- Smoother engine performance
- Added power (some quantified it in a 10% to 15% order of increase) which improved performance during take-off and flight and improved the lifting capability of the aircraft. This improved load capacity on the hopper, independent of the temperature in the field, made it possible to take off with loads of 500 kg.
- Cooler engine temperatures allowing regular crop dusting operations at high ambient temperatures
- Safer engine operation due to resistance to vapor lock
- Cleaner emissions from the engine (and pleasant smell of alcohol rather than hydrocarbons)

#### *Economic Advantages*

- A Pawnee, during a typical crop dusting operation, consumes 60 liters of gasoline per hour, representing a cost of \$85.71US -- approximately \$270.00 R (Reais, the Brazilian currency) using 2004 currency exchange rates. The ethanol, even considering a maximum increase in consumption of 30% over gasoline, 78 liters, costs \$28.47 US (\$89.70 R). The difference generates a direct reduction of costs per flying hour of around \$57.24 US (\$ 180.30 R). With an average of 450 flying hours during the harvest season, a savings of \$25,758.00 US (\$81,135.00 R) is generated by each operating aircraft

- The TBO (time before overhaul) of the Lycoming 0-540 engine, either 235 HP or 260 HP, recommended by the manufacturer in the case of the crop dusting operations is 1500 hours. Due to ethanol's combustion's characteristics, it has been determined by field experience that an additional 1,000 hours, could be flown after the normal 1,500 hours. Considering that the overhaul cost is approximately \$18,000.00 US (R\$ 56,700.00), the cost per hour due to the overhaul is \$12.00 US (R\$ 37,80). On the other hand, flying on ethanol, the cost of the overhaul can be spread through 2,500 hours, reducing the per hour cost to approximately \$7.20 US (R\$ 22.68). The generated savings amount to \$ 4.80 US (R\$ 15.12). For every 2,500 hours flown, the savings would amount to \$12,000.00 US (R\$ 37,800.00) (Tangará, 2006 – Personal Communication)

Furthermore, other factors result in operational savings due to cooler temperatures and less wear on the engine. The initial experience in the field proved that with the use of ethanol, spark plugs can be substituted after 500 hours and not every 200 hours as recommended when using aviation gasoline. The costs of conversion to ethanol of the engine and the aircraft are easily absorbed if performed during a standard engine overhaul.

In Brazil, the use of ethanol in agricultural aviation will guarantee the survival and advancement of this sector of aviation. The benefits will be passed on to the consumer who will be able to have the same services at a lower cost. The agricultural aviation companies could also benefit from it by investing the savings in maintenance, research, and further development.

The benefits reported by the Brazilian pilots and operators are the same as those experienced in the US by Dr. Shauck and his research team during over two decades of development efforts and as reported in the technical information submitted to the FAA during the process of obtaining the STC's, and also in numerous papers presented at various international symposia (Alvarez, et al., Ethanol / Avgas Fuel Blends: A Transition Phase for General Aviation, 2006).

### *Current Situation in Brazil: An Ongoing Full Scale Experiment*

Word of the economic and technical benefits of using ethanol as an aviation fuel spread very rapidly in Brazil. Aircraft agricultural spray operators rushed to convert their fleets to ethanol disregarding compliance with legal requirements. Due to the large number of operators converting to ethanol the Brazilian authorities threatened to take legal action against these operators. At that point, upon receiving several requests from Brazil to assist with the conversion of aircraft to use ethanol, Dr. Max Shauck agreed to apply to the Brazilian Aviation Authority to obtain Brazilian validation of the USA FAA STC for the Piper Pawnee aircraft series. The application was formally filed with the Centro Tecnico Aeroespacial (CTA), the Brazilian Aviation Authority, in January of 2003. Many questions regarding technical issues and fuel properties were subsequently raised by the CTA. One of the concerns during the certification validation procedure was whether Brazilian hydrous ethanol was substantially different from USA anhydrous ethanol.

A comprehensive report comparing the characteristics of Brazilian hydrous fuel ethanol, represented by Technical Regulation DNC - 01/91, to USA standard anhydrous denatured fuel ethanol, represented by ASTM D4806, was produced (Zanin, Shauck, Alvarez, Anderson, & Wells, 2006). The conclusion of the report is that both ethanol specifications are suitable to be used in any appropriately converted spark ignition application where materials compatibility issues have been addressed. Furthermore, there is no specification of US anhydrous not covered by the Brazilian hydrous specifications that would preclude the use of Brazilian hydrous as a neat fuel in an appropriate engine and fuel delivery system.

The current situation in Brazil, in regard to ethanol as an aviation fuel, is in a state of turmoil. There is no doubt that ethanol has quickly become a reality in Brazilian aviation. As aviation authority certifications are still being considered, an implicit and unofficial agreement seems to be in place between the aviation authority and the agricultural spray operators.

As per recent information there are about 800-1,000 agricultural spray aircraft currently flying on ethanol in Brazil (Almeida, 2006). These aircraft have accumulated an estimated 600,000 hours of flying on ethanol. Additionally, there are an estimated 150 general aviation single and twin engine aircraft flying on alcohol.

#### *Potential Obstacles*

Although engine and aircraft conversions are being done in some cases without the proper technical information and experience in the rural areas of Brazil, fortunately, no major accidents were reported during this time period due to these conversions (at least officially!). The boost in agricultural aviation promoted by the use of ethanol, has attracted many pilots from the general aviation sector to agricultural spray operations. Thus, pilots with little flying experience and with little knowledge about ethanol fuel operations are now involved in flying agricultural spray aircraft, a type of flying requiring considerable skill, and are flying, in most cases, aircraft with "home made" engine conversions.

Another potential problem is the use of ethanol in the fields that has not been subjected to quality controls or even simple checks for fuel contamination or percentage of water content. Hydrous ethanol has been used by many of these operators who do not have the equipment or the knowledge to check the water content in the fuel in the field.



Compatibility of materials in the engine exposed to fuel with high levels of water could also turn into a major problem.

The combination of these facts could bring setbacks to the adoption of ethanol as an aviation fuel. As the ground transportation sector in Brazil has already experienced in the past, when early technical problems with fuel ethanol cars brought criticism by alternative fuels opponents, mistakes and mishaps in the aviation sector could surely fuel a greater controversy about the use of this fuel in aviation.

An education campaign on the use of ethanol as an aviation fuel should be a priority together with an orderly procedure of application, testing and issuing of STCs for each engine and airframe type. Considering costs and benefits, the economic advantage of alcohol is indisputable. During the last crop season the motto among the agricultural spray operators was unanimously: “If you want to make money you have to fly on alcohol” (Tangará Aviation, 2006 – Personal Communication). There is no doubt though that a strategic plan and an educational program are urgently needed in Brazil to assure a smooth transition to ethanol as an aviation fuel.

The lessons learned in Brazil will be carefully considered in setting up the GAIFA and any other commercial operation on ethanol. The implementation of a carefully monitored program in the Dominican Republic will support the introduction of regulations, certifications and technical educational material to lay the foundation for an orderly adoption of ethanol as an aviation fuel in all countries in the world where utilization of ethanol makes sense.

### *Opportunity for Flight Training*

The decline of the aviation industry after September 11, 2001 greatly affected the flight training industry as pilots released from the airlines rapidly saturated the available aviation job market. However, within a couple of years, aviation in the US and the world recovered and a resurgence of the aviation industry began again. A sharp growth in aviation is now predicted with the number of passengers, currently 4.2 billion a year, expected to more than double by 2025 at a rate of 4% increase per year (Airports Council International, 2006). According to the EASA Website, cargo operations are expected to triple within the same period of time so that air traffic is expected to double by 2017 (EASA Europe, 2007).

China and India are already experiencing considerable growth in the aviation industry as their aviation infrastructure is in the process of being greatly expanded and developed in places where it was non-existent. Air travel in Asian countries will grow 9% per year, with India leading at a rate of 10.4% followed by China at a rate of 8.1% (Airports Council International, 2006). Asia is expected to surpass the US around the year 2025 in both number of air passengers and cargo volume moved.

There is already evidence of a shortage of professional pilots in Europe and in Asia. The growth of the industry in Asia is already attracting professional pilots from Europe. Very shortly, a leap in demand for well-trained professional pilots is expected. At the same time, the United States is losing its standing as the flight training center of the world mainly due to two factors: higher security measures implemented after 9/11 that make it more difficult for students to enter the US, and the rising costs of aviation fuel.

The ongoing expansion of ethanol production in the US is fueled by the increased demand for ethanol to be blended in gasoline as an octane rating booster (10% level in gasoline) and in the E 85% blend (85% ethanol, 15% gasoline) used in flexible fuels vehicles. The growing industry is providing new jobs, decreasing our dependency on imported oil and decreasing our balance of trade deficit. The choice of this renewable, clean burning, domestically produced replacement fuel for aviation gasoline is clearly in the best interest of the United States and general aviation.

### *Clean Airport Programs Background*

#### *The US DOE Clean Airport Program*

In 1996 the US DOE launched the Clean Airport Program (CAP). The RAFDC, at Baylor University, was appointed by the DOE as the national manager of the program. RAFDC was chosen by the DOE for its experience in the development of alternative renewable fuels for aviation and for its educational/demonstration programs carried on throughout the country. Through many years of research and development work, RAFDC had proven the feasibility of alternative fuels for aviation. Additionally, while involved in the research and promotion of cleaner sustainable fuels for aviation, RAFDC had organized and conducted educational programs, seminars, workshops and conferences throughout the US to educate and demonstrate to the aviation community the feasibility of using environmentally compatible systems. Some of these programs were sponsored by the DOE, which had initiated during the same period of time the “Clean Cities Program” (CCP).

The CCP began as a way for communities to coordinate and implement needed changes to their local environmental policies. It encouraged the use of ground transportation vehicles powered by alternative fuels, such as ethanol, methanol and natural gas and by batteries. By implementing the CAP, the U.S. Department of Energy was encouraging communities to take another step toward lessening their dependence on foreign oil while improving the quality of their air (United States Department of Energy, 1996).

The Program supported two main national objectives: 1. improvement of the quality of the air which represented a health hazard for the population and endangering the environment, and; 2. reduction of the United States' increasing economic and political vulnerability due to its dependence on imported petroleum. The program encouraged the use of alternative, clean, domestically produced fuels in aviation as a step toward the solution of these two problems. The CAP, in coordination with the CCP, was aimed at helping airports implement programs that would help reduce their environmental impact and stimulate the adoption of cleaner renewable fuels on the ground and in the air. The basic concept was to recognize airports as microcosms of society where the public expects to see and experience advanced technology in terms of moving people rapidly, safely, and comfortably with all appropriate amenities to make flights effective and pleasurable. The CAP envisioned environmental, energy efficient and renewable energy dimensions in this expectation as long as the technologies were cost effective and arrived at voluntarily.

The first phase of the program involved the implementation of a minimum number of environmentally friendly and compatible systems, both on the ground and in

the air. RAFDC formulated the initial criteria in order to be designated as a Clean Airport. These included: 1. implementing and maintaining a refueling infrastructure for an alternative aviation fuel; 2. guaranteeing at least one initial aircraft and at least one ground vehicle using alternative fuels, and; 3. developing a demonstration/educational program to inform the public on the topic of alternative fuels and air quality.

To apply for designation as a clean airport, it was also necessary for an airport to enlist stakeholders to coordinate and oversee the program, to draft and sign a Memorandum of Understanding (MOU) among them, and to appoint a Clean Airport Coordinator. Five airports were designated as Clean Airports in the first year of operation, including the Will Rogers International Airport in Oklahoma City. During the second year of operation, the DOE, citing potential jurisdiction conflicts with other agencies in charge of aviation and environmental issues, i.e. EPA and FAA, decided to drop the program.

#### *The International Clean Airport Program*

A new program, the “International Clean Airport Program” (ICAP) was promptly organized in coordination with the International Center for Aviation and the Environment (ICAE) based in Canada to continue the efforts initiated under the aegis of the US DOE. The ICAP emerged from the CAP with an expanded scope, to operate as a global mechanism to improve the air transport industries environmental performance, on a cooperative and voluntary basis in an effort to avoid anticipated unnecessary regulation or bureaucratic intervention.

The ICAP developed an ambitious program aimed at addressing air and noise emission problems as well as issues involving the operational arena of airport ground

activities, passenger, baggage, cargo, and mail processing, which had previously received little attention. The mission statement of the program read: “To enhance the economic, environmental and natural resource sustainability along with the image of the aviation industry in the full scope of its operations” (International Clean Airport Program, 1998). The ICAP strategy, based on a multi-step implementation program was to first consider airports’ current circumstances, ongoing programs and future development plans in order to determine each phase of implementation and priorities. The program aimed at creating a situation where voluntary actions would avoid restrictive regulations and would operate a flexible organizational structure thereby encouraging creativity and wide support.

The criteria for airports’ participation in the program were to: 1. establish a stakeholders group, 2. appoint an International Clean Airports Program Coordinator, and; 3. develop a workable airport environmental program. The implementation and timing of each phase was going to be determined by the stakeholders designated to produce a MOU outlining the goals of the program and the means to achieve the goals and its time frame, including periodic evaluations. The MOU also specified tasks that would improve the overall airport environment, raise public awareness of energy efficiency, alternative fuels and renewable energy technologies, highlighting environmental programs and raising the airport public image. The plan would function within the parameters of safety, cost-effectiveness and non-interference with the airport efficiency.

The main concerns involved with the environmental impact of airports had traditionally been noise and emissions. Although those are the most obvious, other airport activities, which significantly affect the environment, have received little attention. Some of these activities are concerned with the operation of ground equipment

on airport premises, transfer of baggage, cargo, mail processing, and passengers' vehicle traffic around the airport. Furthermore, airports use large portions of land, contribute to air and ground water pollution, produce vast amounts of waste, and consume excess energy. The aviation industry has been rather slow to voluntarily participate in any meaningful energy and waste reduction strategies.

The ICAP developed a list of environmental issues and potential solutions that could be implemented in an order of priority defined by each airport. This list included environmental pressures as defined by the ICAO: 1. global impacts, such as greenhouse gases, depletion of the ozone layer and air pollution; 2. local impacts such as surface water, soil, and ground water contamination, waste disposal, noise emissions; 3. broad impacts such as over-consumption of resources, natural resource conservation and sustainable development; 4. environmental laws and legislation, technology transfer and development, development and coordination of environmental standards, and collection and analysis of aviation industry-wide statistical data.

The program envisioned providing ISO 14000 (International Organization for Standardization) and EMAS (Eco-Management and Audit Scheme) coordinators for ICAP and was developing distance learning programs for interested parties in order to avoid traveling. The ICAP scope was to take advantage of existing information and knowledge in order to develop managerial tools to implement a well-coordinated, comprehensive, efficient and cost-effective environmental management program. The focus of the initial effort was to develop a systematic approach that would benefit the replication of programs proven to work at other airports, especially in dealing with global issues. The next focus was the creation of a structure in charge of information exchange

and expertise as well as research and development aimed at solving common problems and to promote collaboration within the aviation industry to take advantage of the best technologies developed around the world. ICAP would insure coordination and collaboration among the several segments comprising the aviation industry: airlines, airport management, air traffic control, government agencies, aircraft and engine manufacturers, military and general aviation, policy makers, employees, municipal planners, citizens, and all other organizations and individuals involved.

An international airport, the Palm Springs Airport in California, was designated, in the spring of 1998, under this program. This designation was very well received by all the local, state and federal organizations involved in the program. It represented a success in terms of renewable energy systems and programs implemented, in and around the airport. The media provided extensive coverage of the event and of the ongoing implementation of cleaner and more compatible technologies.

Despite the positive reception of the Palm Springs Airport designation, federal, state or private organizations in the US showed no concrete interest to support the ICAP program. As mentioned earlier, the program had been managed and maintained by the personal time and commitment of the author and her colleagues at RAFDC and ICAE.

The program management of RAFDC and ICAE then asked whether the effort should continue on this level or whether quality management should be assembled to advance this integrated system into profitable private sector enterprise. At this point RAFDC, being affiliated with a non-profit institution and mainly interested in educational and research programs, decided to shift its focus back to research and development efforts in the fields of alternative aviation fuels and air quality monitoring with



instrumented aircraft, while maintaining close collaboration with ICAE whose main focus remained the ICAP.

### *Lessons Learned*

The situation has changed considerably since the late 1990s. The increased knowledge accumulated over recent years on the environmental impact of aviation emissions, coupled with the latest reports on global climate change, is pressuring the aviation community into improving its environmental record by adopting programs to alleviate its environmental impact.

The lessons learned from the significant experiences of developing and managing the CAP and ICAP programs, inspired a different approach to the creation of a “Green Airport”. The “Green Airport” in the Dominican Republic will start from scratch and it will start small with the implementation of the GAIFA.

The GAIFA will represent the foundation for the “Green Airport”, the one that will provide the support and the human resources to implement and integrate each subsequent program, system or technology in a modular manner as the airport grows. Concepts and programs will be added that adhere to the principles of sustainability and environmental compatibility and that will benefit the local, social and economic conditions. Locally produced biofuels will be used together with renewable energy systems. The idea behind the GAIFA is to produce a simple working model, starting with a small number of aircraft and students that will grow as conditions allow, in an innovative program where the best and latest renewable energy technologies will be gradually integrated.

## CHAPTER THREE

### Methodology

Resources utilized to produce this document include:

- Past research and development conducted on alternative fuels for aviation
- Data and information from past demonstration and educational programs and record flights utilizing alternative aviation fuels
- Data obtained during certification procedures with the Federal Aviation Administration (FAA)
- Ongoing research on using blends of ethanol and Avgas in aircraft conducted under a contract with the FAA
- Ongoing research on reducing emissions of ethanol powered aircraft using a catalytic converter conducted under a grant with the FAA
- The Brazilian field experience with agricultural spray aircraft utilizing ethanol
- Personal experience of the author managing the US DOE Clean Airport Program (CAP) and the International Clean Airport Program (ICAP)
- Information gathered during visits to the Dominican Republic (DR)
- Conferences organized and attended in the DR
- Discussions and interviews with Dominicans and Haitians
- Meetings with representatives of Foundations, government agencies, researchers and university officials in the DR
- Papers and documents produced by the Re-Birth of Hispaniola Program
- Use of the World Wide Web to gather data and information

### *How Resources Were Utilized to Build the Model*

Extensive prior experience with using alternative fuels in piston engines, testing aircraft and research conducted at the Baylor Institute for Air Sciences (BIAS), under grants and contracts with the FAA, has provided a wealth of information and material that was used in the development of this model to justify using training aircraft on ethanol. The author was directly involved in writing and administering all of the proposals throughout the past 20 years at the BIAS and in the research conducted on all of these programs. The following is a list of selected programs:

- Ethanol as an Aviation Fuel Education (Texas State Energy Office)
- Ethanol Education/Demonstrations (Nebraska DOE)
- Research and Development of Ethanol as an Aviation Fuel (Federal Aviation Administration)
- Demonstrations/Educational Programs (Great Lakes Regional Biomass Program)
- Piper Pawnee Certification (US DOE WAPA, Corn Growers South Dakota, North Dakota, Nebraska, Alabama)
- Demonstration/Implementation of Ethanol as an Aviation Fuel (US DOE)
- Research and Development of Ethanol as an Aviation Fuel (US DOE)
- First International Conference on Alternative Aviation Fuels (US DOE- FAA- Private Organizations)
- Southeastern Regional Biomass Energy Programs (U. S. DOE SERBEP)
- Certification of a Cessna 152 on ethanol (Texas Higher Education Coordinating Board)
- Research and Testing of Alternative Fuels for Turbine Engines (Texas Alternative Fuels Counsel)
- Testing of Additives to Biofuels for Turbine Engines (MDEChem Inc.)

- Second International Conference on Alternative Aviation Fuels (US DOE Western Regional Biomass Energy, US EPA, FAA, Environment Canada, Private Industries)
- US Trainer T3 Study Program (US Air Force --subcontract SAIC)
- Development of Ethanol and Avgas/Ethanol Blends as Alternative Fuels for General Aviation” (Federal Aviation Administration)
- Ethanol as an Aviation Fuel: Emissions Reduction (Federal Aviation Administration)

The ongoing research being carried out under a current contract and grant with the FAA (Contract number TFA03-01-C-00022 and Grant number 02-G-035) has provided validation of past data on the technical characteristics of ethanol as a fuel for aviation and has also provided the data used to assemble the graphs shown in Chapter Four. These data provided the base to calculate the average range and fuel consumption of the Cessna 152 that will be used at the “Green Airport” International Flight Academy (GAIFA). These numbers were then used to calculate the total fuel needed to run the GAIFA for the first year of operation. Ongoing studies also provided the most recent emission testing results which were used to compare emissions of ethanol and Avgas in Chapter Four.

Past experience on organizing and managing the US Department of Energy (US DOE) Clean Airport Program (CAP), and later the International Clean Airport Program (ICAP), provided the author with the background on issues related to the environmental impact of aviation and the implementation of programs aimed at alleviating these concerns. The lessons learned on those programs were important in deciding the structure of the “Green Airport,” to begin simply with the establishment of the GAIFA and gradually integrating additional programs.

The author made numerous visits to the DR. The first visit, in November 2004, provided the opportunity to gain a general understanding of the circumstances related to the social and economic aspects of the two countries sharing the island, the DR and Haiti, the environmental challenges and the problems related to energy supply and energy independence. It was during that first visit that a preliminary account of natural resources in the island, together with the existing tourist and aviation infrastructure already in place, provided evidence that the DR was an ideal place to launch the concept of the “Green Airport”.

During a series of meetings with local experts, sufficient information was obtained to create a preliminary presentation to introduce the concept of the “Green Airport” to the local constituencies. Since the idea was immediately enthusiastically accepted by local representatives, a flight was organized to look at the potential sites for the airport. The pilot of the aircraft flown around the island was the former DR Minister of Environment, Dr. Frank Moya Pons, who had ratified in 2002 the Kyoto Protocol for the DR. Dr. Moya Pons, an accomplished author and renowned economist and historian, was also one of the most knowledgeable people in the DR about environmental issues and their social and economic implications. The flight provided the opportunity to see potential sites and to take numerous pictures of the countryside and of the existing aviation infrastructure in the country. After the flight, a series of discussions with Dr. Moya Pons, members of the aviation community, government and local foundations representatives, took place to determine the best location for a “Green Airport”. Below is a picture of an ideal site photographed during that first flight, the “Cuevas de las Maravillas” airstrip, then still under construction.



Figure 1 The airstrip of La Cueva de las Maravillas located close to sugar cane plantations and a distillery

The interest created in the DR for the program laid the basis for the next working meeting. This was a conference jointly organized by the BIAS and the FUNGLODE (Fundación Global Democracia y Desarrollo) that took place in Santo Domingo in May 2005. The conference focused on the development of a biofuel industry and the newly established governmental energy strategic plan to promote biofuels and renewable energy. The plan for the “Green Airport” was presented to government officials, aviation authorities and representatives of local universities and foundations. Cooperation agreements were signed on that occasion (MOU among Baylor University, FUNGLODE and the Instituto Dominicano de Desarrollo Integral (IDDI), 2005).

Dr. Moya Pons visited BIAS in the summer of 2005 to observe first hand the accomplishments of the program and to further discuss the implementation of the “Green Airport” program.

Another visit was made to the DR in December 2005-January 2006 to meet with numerous constituencies in the island and to work out details on the program. Prior to

this visit, political problems had developed between the “Cueva de las Maravillas Foundation”, responsible for the land and the airport where the “Green Airport” originally was to be established and the government. The problems, although resolved in the end, delayed progress on the program and other locations were eventually considered for the establishment of the first “Green Airport” in the DR.

In March 2007, BIAS organized another conference in coordination with the Re-Birth of Hispaniola Program and the INTEC (Instituto Tecnológico de Santo Domingo) in Santo Domingo. This meeting focused on the “Green Airport” implementation, in a more concrete and detailed manner, and its integration with newly established biofuels and renewable energy programs in the island. The conference provided an opportunity to understand the country’s progress of the implementation of the national strategic energy plan and also to form new relationships with universities and the local aviation network. The “Green Airport” project received prominent attention at the conference. During this time the BIAS representatives and some of the BIAS External Advisory Board members met with the President of the DR, Dr. Leonel Fernandez to discuss the program. The President provided his full support to the concept.

The information gathered throughout these visits together with information obtained from reports and environmental assessments was used in this document to analyze figures on available land and various crops efficiencies to produce biofuels in the DR and to compute the estimated new jobs the biofuel industry would create. The figures were then used to work out the amount of land necessary to produce the fuel for the Green Airport International Flight Training Academy (GAIFA) and the social and economic benefits that would derive.

During the visits to the DR, several trips were made to the mountains where Dr. Charles Frantz Flambert, a renowned agronomist, has established his research facilities. Dr. Flambert, a former minister of Agricultural in Haiti, has become an authority in the research and development of agricultural feedstocks grown to produce biofuels. Dr. Flambert travels the world to learn about different varieties of crops that could be cultivated in the DR. After testing them in the DR, he compares them with other varieties to identify those that are most efficient and best suited to local conditions. Dr. Flambert provided the figures on yields of various crops in the DR. He is a very conservative scientist, and his figures show less yields than reported by others. These figures were utilized for the calculations shown in Chapter Four. Below are some pictures of Dr. Flambert with one of his sweet sorghum varieties.



Sweet Sorghum GE-3 48 days



Sweet Sorghum GE-3 76 days

Figure 2. Dr. Flambert with sweet sorghum varieties



The calculations used to show the reductions of CO<sub>2</sub> reported in Chapter 4 are based on the assumptions made about the initial fleet of aircraft to be utilized at the GAIFA. The most conservative factors provided by the Brazilian study mentioned in Chapter Two were used for these calculations. The factor of 2.16 t CO<sub>2</sub> eq / m<sup>3</sup> was applied to the total quantity of fuel estimated to be used at the GAIFA during the first year of operations. The difference in range between ethanol and Avgas was taken in consideration by applying the equivalence of 1 liter of ethanol = 0.75 liter of gasoline (since up to 25% more fuel by volume is used when using ethanol rather than Avgas in this particular aircraft engine). The equivalent CO<sub>2</sub> emissions reduction released into the atmosphere when using ethanol rather than Avgas were calculated applying straight forward conversion factors and multiplications.

Economic benefits were also computed through the application of the most conservative factors. A cost of \$ 2.50 per gallon for ethanol is assumed in all fuel cost comparisons even though current average cost in the US is below \$2.00 per gallon and is below \$1.00 per gallon in Brazil. Likewise, the cost for Avgas used in the computations, \$4.50, is the current average cost in the US, while in the DR Avgas is currently over \$ 6.00 per gallon (Bros, 2007—Personal Communication).

## CHAPTER FOUR

### The Model

The Dominican Republic was identified as the ideal location to develop a “Green Airport” where local renewable energy resources will be integrated with modern technologies to create a model of sustainability for aviation.

The Green Airport will involve many activities, including:

- An international flight training academy
- Academic courses coordinated and provided by local and international universities, seminars, short courses, semester-long courses and international conferences
- Educational/demonstration programs to show the feasibility of new renewable energy technologies
- Research and certification programs on alternative fuels for both piston and turbine engines
- Agricultural Spray Aircraft operating on biofuels supporting sustainable agriculture practices
- Eco-tourism activities and recreational flying using biofuel powered aircraft
- Use of small efficient aircraft powered by renewable fuels for environmental monitoring and security patrolling

The implementation of the Green Airport International Flight Academy (GAIFA) on biofuels will represent the first phase of the program, the one providing the foundation and the human resources to develop an off-the-grid, full-scale Green Airport. The Green Airport will utilize biofuels, solar, wind and photovoltaic technologies serving as a model of sustainability for the aviation world. The objective is to showcase and eventually

replicate the Green Airport model worldwide where it could be adapted and suited to local resources, climate, social and economic conditions.

### *The Dominican Republic, an Ideal Location*

The creation of a Green Airport in the Dominican Republic (DR) would serve as a catalyst supporting the objectives of a broader national plan to meet growing energy demands, create new jobs in the rural sector, and adopt sustainable energy systems. The high visibility of the program would, among other benefits, contribute to the education of the population regarding local and global environmental challenges and available solutions.

The ideal location for the airport, in the vicinity of sugar cane plantations and ethanol producing distilleries, will minimize the cost of fuel transportation while maximizing efficiency and providing new opportunities for employment in the countryside. Other aspects contributing to the choice of the DR as the ideal site for this program are:

- The natural beauty of the island, attracting tourists from around the world
- Ideal climate, sun and wind
- Abundant raw materials to produce biofuels
- Available work force to grow biomass and process it into fuels
- Existing tourism infrastructures
- Existing network of airports and aviation community. The DR is the destination of regularly scheduled flights from Europe, South and Central America and the USA

In May 2005, during a follow-up conference organized by the Baylor Institute for Air Science (BIAS), in coordination with the “Fundación Global Democracia y

Desarrollo” (FUNGLODE) and other local foundations and organizations in the DR, agreements were signed to firm up plans for the establishment of the Green Airport program and the GAIFA (MOU between Baylor University, FUNGLODE and the Instituto Dominicano de Desarrollo Integral (IDDI, 2005).

### *The GAIFA*

The international growth in aviation, the potentially high number of foreign pilots who would like to avoid the bureaucratic burdens involved in entering the USA, and the economic benefits resulting from using biofuels are strong incentives that will attract student pilots and professional pilots to the GAIFA in the DR. Other appealing factors include competitive costs, the existing network of international airports on the island, ideal climate to fly year-round, sea and mountain training conditions for flying and tourist attractions and infrastructure.

Currently there are over 1,000 approved flight schools in the US (FAA Flight Schools, 2007) representing a \$2 billion industry. A number of the flight schools are located in the South of the US, but only one flight school is in the Caribbean, in Puerto Rico. The fast growing market of commuter and low fares airlines is expected to rapidly increase the demand for professionally trained pilots throughout the world.

Initially, the GAIFA will recruit students from North, Central and South America in order to start operations according to the FAA approved procedures. Following the standardization of flight training licenses and regulations in the EU, the addition of the European Aviation Safety Agency (EASA) approved procedures and instructors will also be considered. The GAIFA will target students seeking to obtain their pilot licenses who are also interested in learning and being involved in environmental issues and

occupations that combine aviation and environmental work. These students will have the opportunity to enroll in academic courses and be involved in research programs during their flight training. The GAIFA will offer four year approved BS degrees in aviation sciences and environmental sciences with the pilot/scientist option as the core of the program and the opportunity to pursue graduate studies in related areas (this will involve agreements and exchange programs with US institutions and local institutions).

In February 2007, the President of the DR, Dr. Leonel Fernandez, made a personal request to the President of Baylor University that the Cessna 152 belonging to Baylor be sold to the Spirit of Hispaniola, a non-profit organization created to spearhead the Green Airport in the DR. The sale was approved and the aircraft has been recently purchased by the Spirit of Hispaniola. This is a symbolic and historical aircraft, since it was the first aircraft to be certified on a renewable fuel and it will be the first training aircraft based at the first Green Airport.

In March 2007, a conference took place at the Instituto Tecnológico de Santo Domingo (INTEC) in the DR, to discuss the Green Airport project and the progress on the ongoing renewable energy programs on the island. On this occasion, contacts were made and meetings held with local foundations, with Aerodom, the organization that now manages the major airports in the DR and with the two local universities, the INTEC and the Universidad Iberoamericana (UNIBE) that would best support the implementation of the Green Airport. Aerodom pledged its full support to the program. A decision was made by the participating organizations, the local foundations, INTEC and UNIBE, Aerodom and BIAS, to go ahead with the first phase of the program implementation, the GAIFA.

The following assumptions and initial economic and environmental benefits analysis involved in the development and implementation of the GAIFA were made by taking into consideration previous experience, and preliminary information.

*Set of Assumptions for the Establishment of the  
Flight Academy on Biofuels*

The primary concern in the preliminary phase of development of any activity is the assessment and determination of the ideal initial size of the operation. Even with results of research in hand of the potential market, in this case the number of potential students, the level of uncertainty for this type of operation is still very high. Unless considerable resources are spent in extensive market analyses and surveys, the interest in this program can only be verified once operations start. The wisest plan of action would be to start small and to grow as activities grow. However, in the case of a flight training academy, there are some efficiency factors that need to be considered in order to match the minimum equipment necessary to start operations with the optimal number of personnel required to carry on activities. Considering the average number of aircraft a full-time aviation mechanic can maintain and the number of students a flight instructor can handle, a decision was made to start the activities with the following aircraft fleet:

5 Cessna 152 (C-152)

1 Piper Aztec

1 Flight Simulator

1 or 2 Cessna 172 (C-172) would be added, as needed, on the second year of operation.

The choices of aircraft types are dictated by the current certification available for the use of ethanol as an aviation fuel. The C-152, the most popular trainer in the world, is already certified by the FAA to fly on ethanol. The C-172 is currently undergoing FAA certification in the US. The Piper Aztec's engines are already certified while a certification is needed for the airframe. For planning purposes, the assumptions presented here are based on keeping this first fleet busy throughout the year, making allowances for interruptions due to weather conditions.

Since the Flight Academy would be outside of the United States, it would have to be structured under FAA Rules Part 61 (Federal Aviation Administration, 1978). These will require: 1. a minimum of 40 hours of flight training (20 with an instructor and 20 solo) to obtain the private license and; 2. a minimum of 250 hours of total flying time to obtain instrument and commercial licenses (20 commercial + 30 instrument with an instructor). To obtain a multiengine license a minimum of 10 hours of flying is required (all of them with instructor) which can be included in the 250 total necessary for the commercial license.

#### *Assumptions on Aircraft Utilization*

1. One can count on approximately 40 weeks of flyable weather conditions considering the historical data from the DR National Weather Service Office (period 1971-2000 see Figure 3 below)
2. Each C-152 aircraft will be flown 6 days per week, for 7 hours per day. This would result in:  $6 \times 7 \times 40 = 1,680$  hours per aircraft  $\times 5$  aircraft = 8,400 hours total
3. Dividing the total number of hours, 8,400 by 250 (minimum hours required for the commercial license) results in 33.6 as the number of full-time students, pursuing a commercial license, which the academy would be able to handle during the first year of operation. This is just an approximation since in reality, and in particular at the onset, there will be a mix of goals for different students who will not necessarily pursue an intense commercial professional pilot course but could indeed be interested in pursuing certain licenses or just portions of licenses. However, for planning purposes, 33 full-time students is the assumption for the first year.

**National Weather Service Office**  
Period: 1971 - 2000

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Measuring Station :

**La Romana (La Romana Int'l Airport)**

Lat: 18.417N Lon: 68.967W

Elev: 23M (75.4 FT)

Location with respect to the Green Airport: 5 NM EAST

	MONTH												
PARAMETER	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	AVERAGE
Normal Precipitation (mm)	27.1	26.2	30.8	48.8	92.2	43.7	46.1	100.6	141.2	210.7	98.1	47.4	76.1
Highest Recorded in 24 hrs (mm)	78.6	33.4	30.8	55.0	117.5	133.2	59.4	209.3	207.8	218.4		68.0	
Date (dd/yy)	19/73	19/71	5/78	27/74	26/80	10/79	26/71	31/79	16/75	25/78		6/80	
Days of Rain (normal)	4.4	4.6	4.5	5.3	7.0	4.0	6.0	8.0	8.6	10.5	9.0	6.1	6.5
Average Normal Temperature (°C)	24.3	24.5	24.8	25.5	26.4	27.4	27.9	27.8	27.5	27.1	26.2	24.9	26.2
High Normal Temperature (°C)	29.7	29.9	30.3	30.8	31.1	32.1	32.8	32.7	32.2	31.8	31.0	30.1	31.2
Highest Temp. Recorded (°C)	32.8	33.0	34.0	35.0	34.0	36.0	36.6	37.0	37.0	37.7	34.0	32.9	
Date (dd/yy)	31/73	22/74	11/73	14/75	7/78	29/74	6/74	16/74	12/72	18/81	21/73	8/81	
Low Normal Temperature (°C)	19.0	19.1	19.3	20.2	21.7	22.6	22.9	22.9	22.7	22.3	21.4	19.7	21.2
Lowest Temp. Recorded (°C)	14.0	15.0	15.5	15.0	16.9	20.0	20.8	20.8	19.5	19.7	18.2	15.0	
Date (dd/yy)	29/76	15/78	16/81	3/76	1/81	27/81	25/79	24/79	28/76	27/81	23/79	15/75	

98.1 Estimate value based on average on years 1966 to 1980 only.

Figure 3. DR National Weather Service historical data. Copied from the National Weather Service Office



### *Cost of Fuel*

The average cost of aviation gasoline (Avgas) is \$ 4.50 /gallon (AirNav.com). The US cost is used for the sake of using the most conservative figures since in the DR and the rest of the Caribbean the cost of Avgas is over \$ 6.00. The average cost of ethanol is \$ 2.50 /gallon. This is again a conservative average figure since currently ethanol is below \$2.00/gallon in the US.

Aircraft flying on ethanol consume 10% to 25% more than when using Avgas, depending on engine and engine compression ratio. This is the consumption experienced when a pilot learns to lean the mixture when flying on ethanol. We will use the worst case figure of 25%, in order to make a conservative estimate. In this case, adjusting for the higher fuel consumption, 1.25 gal of ethanol would be used in place of 1 gal of Avgas:

The C-152 burns approximately 8 gal/hour:

The cost/hour on Avgas would be:  $8 \times 4.50 = \$ 36.00$

The cost/hour on ethanol would be:  $10 \times 2.50 = \$ 25.00$

This would result in a saving of:  $\$ 11 .00$  /hour

The cost saving on fuel per year, per C-152 aircraft would then be \$ 18,480.00.

The total savings for 5 C-152 using ethanol rather than Avgas would be \$92,400.00.

Assuming 10 hours of multiengine time per student, we obtain a total of 330 hours of AZTEC time. We will use the same worst case figure of 25% more fuel consumption when burning ethanol.

The AZTEC burns approximately 24 gal/hour:

The cost/hour on Avgas would be:  $24 \times 4.50 = \$108$

The cost/hour on ethanol would be:  $30 \times 2.50 = \$ 75$

This would result in a saving of:  $\$ 33/\text{hour}$

The saving per year in fuel for the AZTEC aircraft would total \$ 10,890.

The total saving in fuel for all 6 aircraft would be \$ 103,290.00 a year.

#### *Aircraft Cost Per Hour*

Table 2. C-152 Aircraft Costs

C-152 Expense	Dollar Amount Per Hour
Fuel \$2.50 / gal. x 10 gph	\$25.00
Maintenance	\$10.00
Insurance Liability Plus Hull (\$10,000 / yr / 1,680 hours)	\$6.00
Hangar Space (\$13,000 / year / 6 AC)	\$2.00
Engine Fund (2,000 hours TBO @ \$2,000 overhaul)	\$10.00
Total Cost Per Hour	\$53.00

Table 3. Aztec Aircraft Costs

Aztec Expense	Dollar Amount Per Hour
Fuel \$2.50 / gal. x 60 gph	\$150.00
Maintenance	\$ 20.00
Insurance Liability Plus Hull (\$10,000 / yr / 330 hours)	\$ 31.00
Hangar Space (\$13,000 / year / 6 AC)	\$ 2.00
Engine Fund (2,000 hours TBO @ \$2,000 overhaul)	\$ 25.00
Total Cost Per Hour	\$228.00

Flight Instructors rates will be \$ 30/hour (instructors are paid by hour only).

The assumption is that there will be 33 full-time commercial license students during the first year of operation. Each student will fly an average of 250 hours per year in the C-152 and 10 hours/year in the Aztec.

C-152 will cost students  $\$ 68/\text{hour}$

Aztec will cost students  $\$288/\text{hour}$

### *Cost of Licenses*

Cost of private license:

\$ 2,720/aircraft + \$ 600/instructor + \$1,200 ground school = \$ 4,520

Cost of commercial, instrument and multiengine licenses:

\$ 200 hours X \$68/hour = \$ 13,600/C-152 aircraft + \$ 2,880/ Aztec aircraft + \$ 1,500/instructor + \$ 500/simulator + \$ 2,000 ground school = \$ 20,480

Total cost for all licenses: \$ 25,000

Prices for comparable flight training schools in the USA range from \$ 35,000 to \$50,000, depending on aircraft utilized and locations (Texas State Technical College, 2007) (AOPA , 2007)

When considering the minimum hours of flight required, the savings in fuel costs for each student flying in aircraft utilizing ethanol rather than Avgas, would total approximately \$ 3,000 (again, this would be the most conservative figure).

### *Sustainability and Energy Crops in Hispaniola*

Although the Island of Hispaniola is blessed with ideal land morphology and climate that support the growth of a wide variety of crops and agricultural products, the two countries sharing the island, Haiti and the Dominican Republic, have both been challenged by environmental degradation. However, the Dominican Republic, despite its soil erosion and water pollution issues still enjoys a growth in its agricultural production while the situation in Haiti has deteriorated to a full-blown environmental catastrophe. In Haiti, the political and economic turmoil of the past decades have contributed to an uncontrolled deforestation caused by the harvest of timber for firewood that has escalated to 96% degree of deforestation. Haiti is the poorest nation in the Western world and

poses a great challenge to the many international cooperation organizations currently supporting development programs on the island. Both countries, lack indigenous production of fossil fuels and are completely dependent on Venezuela for their transportation fuel, which leaves them extremely vulnerable to any major supply interruption (Mendelson Forman, 2007).

The Re-Birth of Hispaniola Project, supported by the international community, offers new hope for Haiti and the Dominican Republic, to develop a local de-centralized bio-energy industry that would rapidly create a sustainable biofuel economy. The proposed program, already in the first stages of implementation, holds great promise to create new jobs and to provide energy and liquid fuels while restoring the environment through reforestation and sustainable agriculture practices. The Re-Birth of Hispaniola project is working to coordinate efforts with governmental and non-governmental organizations, foundations and the private sector to create the basis for the development of the new bioenergy-biofuels industry. This labor intensive industry would resolve many of the economic and social challenges facing the two nations by mitigating the growing urban migration and the resulting economic and social upsets and environmental pollution. Providing quality rural jobs and adequate community services, can help re-establish the social structure of rural villages and allow the expansion of sustainable activities and opportunities. These positive changes may result in a long-term solution to the socio-economic problems that plague both countries. (Bros, 2005)

The presidents of the two countries, René Préval and Leonel Fernández, have recently signed an agreement to cooperate in providing technical and educational support. There seems to be a renewed willingness to cooperate and renewed awareness of the

interdependence of the two countries that is inspiring the commitment to finding solutions to chronic problems such as border trespassing and mass emigration from Haiti. Within this scope, the Spirit of Hispaniola bioenergy program has initiated the planting of *Jatropha Curcas* trees along the border between the two countries. These trees, which can be grown in fairly arid soils, improve soil erosion and provide high yields of oil producing seeds that are ideal for the production of biofuels. This program can help provide an opportunity for cooperation and for peace building between the people of each country while providing energy independence.

The prospect of the *Jatropha Curcas* becoming a major energy crop is generating considerable interest worldwide. The rapidly developing bioenergy industry is exploring the potential of cultivating energy crops in ideal locations around the world for the production of biofuels. The Caribbean region is recently attracting widespread attention for its ideal climatic conditions and the potential to produce oils from seeds and for the production of ethanol from sugarcane. The utilization of ethanol as an automotive fuel, either in small (5 to 10%) or larger percentage (85%) blends in gasoline, or neat (100%) as in Brazil, is raising the interest of governments of the potential to gradually adopt biofuels.

Major changes have been experienced during the last 2-3 decades in the agricultural sectors of the countries sharing the island of Hispaniola. Traditionally, both countries were major producers of sugar cane. Due to the decline in the international sugar markets during the '80s, the governments initiated the privatization of large areas of land previously used for sugar cane plantations. Although, in some cases, the privatization brought improvements in efficiency through the adoption of modern

technologies, for the most part, manipulations and consequent swings of sugar prices in the world market, led to the abandonment of large sections of land formally used for sugar cane plantations (International Resources Group, Ltd., 2001).

In Haiti, production of sugarcane has been steadily declining to the point that the country has become a net importer of sugar since the late 1970s; nevertheless, sugar is currently the second major cash crop.

The Green Airport will be located in the DR, and the initial developments on the production of sugar cane and distillation of ethanol will likely occur here first.

Consequently, the following analyses on available resources, land and conditions, will initially be focused on the DR side of Hispaniola, though success could be applied to Haiti in the future.

#### *Ethanol Production in the DR*

During the last three decades, profound changes in trends in the Dominican social structure have considerably affected the economic and agricultural productivity. Before 1980, agriculture represented the major sector of the Dominican economy. A 50% population growth and a steady migration to the cities in recent decades have radically changed circumstances. Tourism has become the mainstay of the economy while manufacturing and financial services have also grown considerably.

Before 1980, sugar cane plantations and subsistence hillside farming represented the principal agricultural systems. Since then, due to the world sugar prices turmoil, the growth of the tourism sector and the rapid changes in social structure in the country, agricultural production has become diversified with a great expansion of rice production and of high-value export crops such as bananas, plantain, yucca and tomatoes. The

problem of soil erosion does not seem to have been exacerbated by the changes in practices since the mass migration to urban centers resulted in the abandonment of hillside plots, where soil erosion was more prominent (International Resources Group, Ltd., 2001).

The rapid population increase and urbanization of the country have brought new challenges; primarily environmental pollution and energy demand. A growing reliance on imported fossil fuels coupled with the increasing demand for energy from workers and families who have migrated from the country to the cities has resulted in precarious conditions on the island and pervasive environmental degradation. Interruptions in energy distribution that cause widespread blackouts, are becoming more frequent and fuel prices are very high and unstable as the country is entirely dependent on Venezuela for its supply of transportation fuels (Bros, Personal Communication, 2005).

In 2005, the President of the DR, Dr. Leonel Fernandez, made bioenergy one of his four top government priorities and asked the Inter-ministerial Commission to implement competitive bidding in order to translate this priority into government policies. The Industry and Commerce Secretariat have approved ethanol imports for gasoline blending in order to provide an incentive to revamp agriculture production of sugar cane and the domestic distillation of ethanol (Bros, Personal Communication, 2005). Table 4 below, provides a snap-shot of the land use potential in the DR.

Table 4. Adapted from “Land Use Capability Classification for the DR”.

Land Class	Km <sup>2</sup>	Percentage of National Territory	General Characteristics of Land Class Unit
I	537	1.1	Excellent for cultivation, high productivity potential.
II	2,350	4.9	Very good for cultivation, few limiting factors
III	3,122	6.6	Good for cultivation, some limiting factors, medium productivity potential with good management.
IV	3,639	7.7	Limited potential for cultivation, appropriate for pasture or perennial crops, with severe limiting factors. Low to medium productivity with management.
V	6,071	12.7	Limiting factors severe, especially drainage. Can be used for pasture or for rice with intensive management.
VI	5,611	11.8	Cannot be cultivated, except for certain perennial crops (such as coffee), pasture or forestry. Limiting factors include topography, soil depth, and rocky soils.
VII	25,161	52.7	Cannot be cultivated, only appropriate for forestry uses.
VIII	1,202,	2.5	Cannot be cultivated, appropriate for protected area or wildlife uses.
Total	47,693	100.0	

*Note:* Does not include 588 km<sup>2</sup> of lakes, islands, and other areas. *Source:* OAS Survey of Natural Resources of Dominican Republic 1967, cited in 1981 CEP.

In 1980, sugar cane plantations occupied approximately 4,025 km<sup>2</sup> of land while in 1998 it only occupied 3,682 km<sup>2</sup>, a decline reported in these two decades approximately of 10 % (International Resources Group, Ltd., 2001). Hard figures are not available for most recent years, but there seems to be a further reduction in sugar cane production with large sections of abandoned or underutilized plantations (Bros, Personal Communication, 2005).

Following a region-by-region survey of suitable land, an estimate has been made of the existing land available to grow energy crops. The main immediate goal of the Re-Birth of Hispaniola program is to plant sugar cane in 180,000 hectares (1,800 km<sup>2</sup>) and sweet sorghum on an additional 60, 000 hectares (600 km<sup>2</sup>). This would result in the



production of 245 million gallons of ethanol (Bros, 2005). The implementation of this program is projected to create 253,000 new jobs in the rural sector (Bros, 2005).

Progress is already being made as the Consortium Tecno-DEAH, a company formed to carry on these programs, has leased an ethanol distillery and has installed a small mill to process 1,000 ton/day of sugar cane next to the distillery. Production has started at the Boca Chica distillery and two other distilleries (Central Romana and AlcoGroup). The group, in coordination with local foundations and EU support, is building a community-based mill that will transform sugar cane to “High Test Molasses” which would then be distilled in the local distilleries.

Current facilities in the DR consist of 3 distilleries with production capacities of 20,000, 40,000 and 75,000 liters per day. All use molasses as raw material. The projected production is to build mills, within the next 10 years, that will process 2 to 4 million tons of either cane or sweet sorghum, to produce around 150 to 300 million liters of ethanol per year (Bros, 2007—Personal Communication).

The Green Airport will be coordinating its activities closely with the Consortium Tecno-DEAH programs and the newly developed biofuel industry in order to maximize the benefits to the local community while assuring the efficiency of operations.

#### *Ethanol Yields from Sugar Cane and Sweet Sorghum*

Comparative observation on the yield of ethanol from various raw materials is provided in Table 5 below. The table was obtained from Dr. Charles Frantz Flambert, an agronomist residing in the DR, who has been conducting extensive investigations and testing on the efficiency of a variety of feedstocks obtained from different countries with similar climatic conditions.

Dr. Flambert has provided the following comments to the data shown in the table based on his own experiences and tests in the DR: *“For Sweet sorghum: 3 crops per year is high, with 2 to 2.5 being a more realistic figure. The average fuel ethanol yields must then be reduced by a factor 2/3 (from 6,500 liters /ha to 4,300 to 5,400 liter/ha) in essence obtaining the same yield per hectare than sugarcane or a bit better”* (Flambert, 2007).

Additionally, Dr. Flambert is of the opinion that soon new varieties of sweet sorghum will become available and yields will increase. The data reported in Table 5 will be used as a basis for calculations of ethanol production and the extent of land necessary to produce the fuel for the GAIFA operations.

#### *Data on the Environmental Impact of the Flight Training Academy*

Considering the number of flight hours calculated for the first year of operation, we will assume a consumption of a minimum of 100,000 gallons of ethanol to be used for the 5 Cessna-152 and 1,000 gallons of ethanol to be used for the twin engine Aztec. This amounts to a total of 101,000 gallons of ethanol necessary for the first year of operation.

#### *Feedstocks and Land Use*

As shown in Table 5, a hectare cultivated with either sugar cane or sweet sorghum will yield approximately 4,000 liters of ethanol—using the conservative figure since the most recent figures are 5,000 to 7,000 liters/ hectare (Omar Bros, 2007 - Personal Communication). This will convert (3.8 liters = 1 gallon) into 1,052.63 gallons of ethanol/ hectare of land, which is approximately 426 gallons per acre. As a reference,

Brazil produces an average of 662 gallons of sugar cane ethanol per acre (Hofstrand, 2007).

Dividing 101,000 gallons of ethanol by 1,052.63 gallons per hectare, we obtain 96, which is the number of hectares necessary to produce the fuel for a whole year of operation at the flight academy (96 hectares are approximately 237 acres). This figure represents a small fraction of the land available for ethanol production in the DR. Moreover, utilizing the data previously presented, where 240,000 hectares of land provide 253,000 jobs, in the DR, this operation will sustain a total of approximately 100 new jobs in the field for the production of the feedstock and in the distillery for the production of the fuel.

Figure 4 illustrates the land required to produce the fuel for the GAIFA operations. It provides comparisons using sugar cane and corn and also the estimated land required if switch grass was used. The table also compares the number of jobs created when either sugar cane or corn is used.

We could also calculate how many acres it would take to sustain a similar operation in the US using corn ethanol. The average productivity in 2006 in the US was 149 bushels of corn per acre (U.S. Department of Agriculture, 2007), and the average gallons per bushel obtained were 2.75, since it varies between 2.5 and 3 depending on the ethanol plant.

Therefore:  $2.75 \text{ gal/bushel} \times 149 \text{ bushel/acre} = 409.75 \text{ gal/acre}$ .

In order to produce 101,000 gallons to operate the current fleet of the GAIFA we would need:  $101,000 \text{ gal} / 409.75 \text{ gal/acre} = 246.49 \text{ acres of land}$ . This would amount to 9 more acres of land if corn ethanol were used in place of sugar cane.

Table 5. Comparative observation on the yield of ethanol from various feedstocks

Parameters	Sugarcane (good soil)	Sugar Beet (Well drained soil)	Raw Tapioca (Medium draught resistance)	Sweet Sorghum (mdr)
Harvesting Cycle	10 to 12 months	5-6 months (2 times per year).	10 to 12 months	4 months (3 times per year)
Water requirement	100 %	70%	35 to 40%	35 to 40 %
Fertilizer NPK requirement	100 %	30-40%	30 to 40%	35 to 40 %
Stalks production in tons/hectare/Yr (X 70 to get liters)	55 to 65 (in the D.R. ~45 in Brazil ~80 in Cali`~120)	No stalk (100-120 tons) 15% of sugar	No Stalk	90 - 140 (Stalks with juice, grown with three cycles in one year)
Yield of sugar / hectare / year	7 to 8 Tons	15-18 Tons	Nil	8 to 12 tons
Additional sugar by starch hydrolysis of grains tons / hectare /Yr	Nil	Nil	11 to 12 tons	2.5 to 5 tons
Total sugar / hectare /Yr	7 to 8 tons	14-17 tons	11 to 12 tons	10 to 17 tons
Average Fuel ethanol yield (anhydrous at 99.5% conc.) (liter / hectare /Yr)	4000 to 4500 (15% more probably in DR)	7800 to 9500	6000 to 6700	5700 (1500 G) to 8000

If the entire USA fleet would use ethanol, currently approximately 300,000,000 gallons/year, (Federal Aviation Administration, 2005), we would need: 300,000,000 gal/409.75 gal/acre = 732,154 acres of land to produce fuel for the entire general aviation piston engine fleet.

Ethanol Required	
Aircraft	Gallons
C-152 x 5	100 000
Twin engine Aztec	1000
<b>Total Required</b>	<b>101, 000</b>

Ethanol Production		
Crop Source	Land Area	Gallons
Sweet sorghum or sugar cane	1 hectare	1052.63
	1 acre	426
Corn	1 hectare	1012.48
	1 acre	409.75
Switch Grass	1 hectare	2470
	1 acre	1000

Sweet sorghum or sugar cane	<u>Required</u> <u>Produced</u>	<u>101 000</u> 1052.63 426	<u>Gallons</u> gallons/hectare gallons / acre
		96 hectares = 237 acres 100 new jobs in the DR	
Corn	<u>Required</u> <u>Produced</u>	<u>101 000</u> 1 013 409.75	<u>Gallons</u> gallons/hectare gallons/ acres
		100 hectares = 246 acres 2 new jobs in the USA	
Switch Grass	<u>Required</u> <u>Produced</u>	<u>101 000</u> 2 470 1 000	<u>Gallons</u> gallons/hectare gallons/ acres
		41 hectares = 101 acres	

Figure 4. Ethanol Production and Land Required for GAIFA Operations

The use of cellulosic ethanol would require less land. In the case of switch grass, the estimated productivity is 1,000 gal/acre of ethanol (McLaughlin & Kszos, 2005). Therefore only 300,000 acres of land would be needed (300,000,000 gal/ 1,000 gal/acre = 300,000 acres of land) as shown in Figure 5 below.

In 2006, the US ethanol production reached 4,855 million gallons (RFA, 2006). If the entire US aviation piston engine fleet were converted to ethanol fuel, it would require only 1/16 of the 2006 ethanol production.

Considering that in the US, a 100 million gallon per year ethanol biorefinery would support about 1,600 jobs (Renewable Fuels Association, 2007), the conversion of

the piston engine aviation fleet to ethanol would create approximately 4,800 new jobs associated with the fuel production.

For comparison, if the same quantity of ethanol fuel were produced in the DR, and exported to the US, 704,225 acres of land would be used creating approximately 270,461 new jobs. This much higher number of jobs in the DR, compared to the US, is due to decreased mechanization, the varied terrains where sugar cane is produced and is based on prior and current experience in the DR (Bros, Personal Communication, 2005).

<b>Sweet sorghum or sugar cane</b>	<b><u>Required</u> <u>Produced</u></b>	<b><u>300,000,000</u> 1052.63 426</b>	<b><u>Gallons</u> <u>gallons/hectare</u> <u>gallons/acre</u></b>
		<b>197,283 ha = 704,225 acres 270,461 new jobs in the DR</b>	
<b>Corn</b>	<b><u>Required</u> <u>Produced</u></b>	<b><u>300,000,000</u> 1 013 409.75</b>	<b><u>Gallons</u> <u>gallons/hectare</u> <u>gallons/acres</u></b>
		<b>296,150 ha = 732,154 acres 4,800 new jobs in the USA</b>	
<b>Switch Grass</b>	<b><u>Required</u> <u>Produced</u></b>	<b><u>300,000,000</u> 2 470 1 000</b>	<b><u>Gallons</u> <u>gallons/hectare</u> <u>gallons/acres</u></b>
		<b>121,457 ha = 300,000 acres</b>	

Figure 5. Land Required to Produce Ethanol for the Entire USA Piston Engine Fleet

If this ethanol were produced in Mexico, it is reasonable to assume a productivity rate similar to the one in the DR, with about 270,000 new jobs created. A recent study by the Inter- Development Bank suggested that by replacing 10% of Mexico petroleum with locally produced ethanol, \$ 2 billion per year would be saved and 400,000 new jobs

would be created (The Economist, 2007). This would be a first but vital step, to attract investment to rural areas and create jobs benefiting local economies and alleviate the mass migration of illegal immigrants to the US.

Since the US would not be able to produce enough biofuels, with current consumption, to satisfy its own domestic transportation market, Mexico and other countries in Central America and the Caribbean could increase their production of biofuels to supply the US. Again, the benefits would be creation of jobs, better living conditions and less emigration. Also, it could affect the political balances in the region, especially the political influence of the President of Venezuela, Hugo Chavez, who has been providing cheap petroleum to his neighbors on long-term loans.

Moving from grain to cellulose feedstocks would provide an even greater opportunity for biofuel production to promote overall agricultural sustainability in Central American countries and also in the US. Decentralized regional fuel production, sourced from a greater diversity of crops, including perennial grasses, would support the gradual achievement of energy independence in all of these countries, while alleviating the pressure on food crops and reducing global warming emissions.

To implement such programs a major shift in trade policies must take place. Trade policies that dump cheap commodities on developing nations are driving away farmers from their own land and causing mass migrations to cities and neighboring countries (Mendelson Forman, 2007). International food aid programs should invest in local natural and human resources rather than waste money on expensive transportation of cheap commodities. The rapid development of biofuels, if implemented properly, rather than placing new stresses on agriculture, would provide new opportunities to adopt

sustainable production of fuels and basic commodities in countries around the world such as the DR and Haiti. Success of such programs will depend largely on international policies and local decisions to keep the long-range vision that would ultimately produce energy and economic independence and possibly improve living conditions of the impoverished of the world while preserving the environment.

#### *Emissions of Ethanol Powered Aircraft*

BIAS is currently working under an FAA grant (Grant number 02-G-035) to reduce emissions by utilizing a catalytic converter specially designed for the testing. Currently, aircraft cannot use catalytic converters because of the lead in Avgas (PBS, 2007). The research and development of this catalytic converter is geared toward being used exclusively in ethanol powered aircraft. Although the testing program using the catalytic converter is not yet complete, results of the baseline testing, without the catalytic converter, confirm most of the trends previously observed in emissions reduction.

Gaseous emissions data were collected for each individual fuel at 24 in MAP (Manifold Absolute Pressure) and 2400 RPM (Revolutions per Minute) (24 X 24). To graph the gas concentrations, UHCs (Unburned Hydrocarbons), CO and NO<sub>x</sub> concentrations were plotted on the y-axis and the Air-Fuel ratio on the x-axis. The analyses of the results clearly show that fuel emissions of UHCs, and CO are reduced when utilizing ethanol compared to those of Avgas (Alvarez, Anderson, & Compton, 2007). NO<sub>x</sub> emissions are a mixed bag as shown in the graphs below.

Figure 6 clearly illustrates the gradual decrease in ethanol emissions of UHCs. Unburned hydrocarbons emissions from ethanol were significantly lower than Avgas in



both the rich and lean settings. From a health standpoint, the substantial decrease in UHCs presents an immediate benefit. This is because the hydrocarbon emissions contain the carcinogen benzene, and many other suspected carcinogens. This is in addition to being principal precursors of ozone.

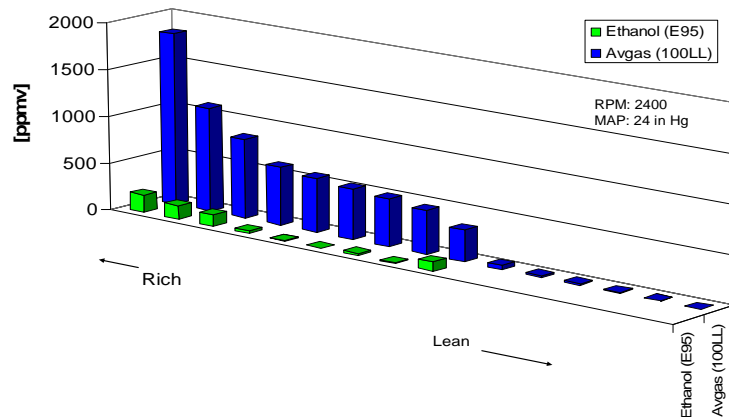


Figure 6 Comparison of unburned hydrocarbons emissions from a Lycoming IO-320 aircraft engine using Avgas (100LL) and ethanol (E95) as fuels

Figure 7 shows that ethanol's  $\text{NO}_x$  emissions percent changes were not as significant as UHCs.  $\text{NO}_x$  emissions decrease significantly on the leaner settings and are higher than Avgas on the richer settings. However, ethanol powered aircraft do not operate on rich mixtures since operating temperatures are much lower on ethanol.

Figure 8 shows a definite trend of decreasing CO emissions for ethanol. CO emissions for ethanol were approximately 3 times lower than Avgas at the richest setting. In the entire operational cycle flying on ethanol, the amount of CO emitted is essentially negligible.

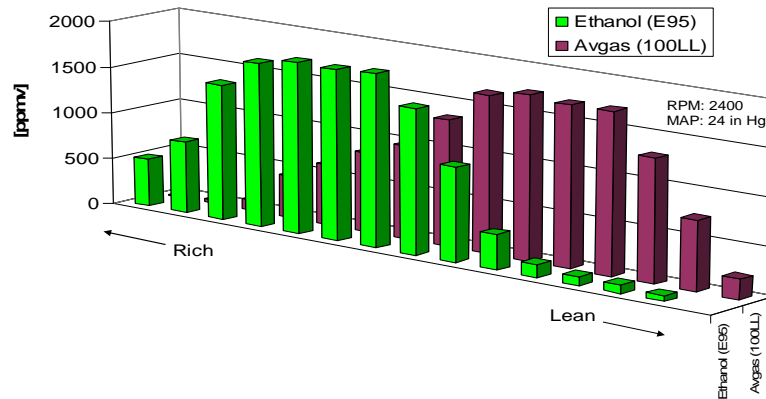


Figure 7 Comparison of NOx emissions from a Lycoming IO-320 aircraft engine using Avgas (100LL) and ethanol (E95) as fuels.

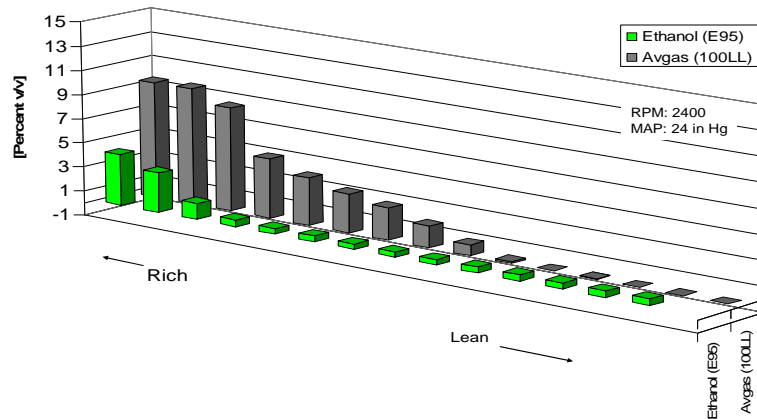


Figure 8 Comparison of carbon monoxide emissions from a Lycoming IO-320 aircraft engine using Avgas (100 LL) and Ethanol (E95) as fuels

An important aspect to highlight is that Avgas requires lead to achieve its high octane number and is the only fuel in the US still containing the toxic element. Ethanol requires no additive to achieve its high octane number. Since the lead must be phased out of Avgas, (United States Department of Energy, 1996) the issue of octane becomes very important, particularly for those engines which are octane critical. These engines use a very substantial amount of the total piston engine aircraft fuel consumed in the U.S. since they are used on the larger twin engine aircraft. These aircraft typically fly several times more hours than small low-powered aircraft. Thus, the issue is economic as well as environmental.

Another consideration in favor of ethanol is that it is also free of toxic chemicals such as benzene and other aromatic components that are present in Avgas. Ethanol exhaust emissions do however contain formaldehyde and acetaldehydes. BIAS emissions tests on these two chemicals have not yet been completed at the time of this writing since they will be performed once the catalytic converter is installed on the aircraft. The Brazilian experience with ethanol provides extensive information on aldehydes emissions from alcohol engines. These are typically higher than those from gasoline, but it must be observed that these aldehydes are predominantly acetaldehydes, not formaldehydes. Acetaldehydes emissions from ethanol are less toxic and produce fewer health effects than the formaldehydes emitted from fossil fuels (Goldemberg, 2002) (US Environmental Protection Agency, 1988). Catalytic converters help significantly in the reduction of aldehydes emissions as well as NO<sub>x</sub> emissions. The results reported above show that overall ethanol is a cleaner burning fuel than Avgas.

### *GHG Benefits*

CO<sub>2</sub> exhaust emissions are not significantly different between Avgas and ethanol. However, the use of biomass feedstock used to produce the ethanol sequesters CO<sub>2</sub> during the growing cycle and leads to a very substantial overall decrease in the CO<sub>2</sub> burden.

In order to evaluate the impact of the GAIFA's initial fleet of aircraft impact on GHG, in CO<sub>2</sub> equivalent, the most conservative value provided by the Brazilian study of a reduction of 2.16 t CO<sub>2</sub> eq / m<sup>3</sup> ethanol will be used ( see Chapter 2 section Green House Gases (GHG) Emission Reductions). The aircraft fleet will initially use anhydrous ethanol. However, the plan is to switch to hydrous as soon as FAA approval is obtained. In the meantime, by using 100% denatured anhydrous ethanol, the equivalent of 1 liter ethanol = 0.75 liters gasoline will be used, as reported for hydrous ethanol in the Brazilian study. This figure also applies to our worst case scenario on fuel consumption in the aircraft, as presented in the section on this chapter on fuel consumption.

Therefore, applying the following conversion factors to 2.16 t CO<sub>2</sub> eq/m<sup>3</sup>:

$$1 \text{ metric t} = 1,000 \text{ kg} = 2,204.62 \text{ lb}$$

$$1 \text{ m}^3 = 1,000 \text{ liters} = 264.17 \text{ gallons}$$

The pounds per gallon of CO<sub>2</sub> equivalent are obtained:

$$2.16 (2,204.62 \text{ lb CO}_2 \text{ eq} / 264.17 \text{ gal}) = 18.026 \text{ lb/gal CO}_2 \text{ eq}$$

Multiplying this result by the total number of gallons estimated to be used at the GAIFA:

$$18.026 \text{ lb/gal CO}_2 \text{ eq} \times 101,000 \text{ gal} = 1,820,626 \text{ lb CO}_2 \text{ eq}$$

The reduction of CO<sub>2</sub> emissions released into the atmosphere resulting from the GAIFA aircraft fleet on ethanol is obtained. This is the equivalent of  $1.8 \times 10^6$  lb of CO<sub>2</sub> reduced when compared to the same fleet operating on Avgas.

Since the long-term vision is to replicate the Green Airport and flight training academy on biofuel in other countries, including the USA, we could also calculate the reduction in emissions for the entire general aviation piston engine fleet in the US. The fleet currently uses approximately 300,000,000 gallons of fuel (FAA, 2007). Substituting this number into the equation above, gives the reduction of equivalent CO<sub>2</sub>:

$$2.16 (2,204.62 \text{ lb CO}_2 \text{ eq}/264.17 \text{ gal}) \times 300 \times 10^6 \text{ gal} = 5.4 \times 10^9 \text{ lb CO}_2 \text{ eq}$$

This figure would change slightly if ethanol made from corn or cellulose was used.

### *Fuel Performance and Range*

During a recent FAA contract (Contract number TFA03-01-C-00022) performance testing was carried out in a Cessna 152 using ethanol. The report is in the process of being completed. Preliminary results, as reported below, confirm the trends observed in past flight testing and certification programs.

The single drawback of ethanol fuel is its reduced heating value which results in a reduction in miles per gallon. Gasoline has 125,000 BTUs per gallon versus 75,000 BTUs per gallon for ethanol. If the thermodynamic efficiencies of ethanol and Avgas were the same, a range reduction of 40% would be experienced using ethanol. However, the higher thermodynamic efficiency of ethanol reduces the loss of range to 15% to 25%, depending on the compression ratio of the engine. This figure is the result of extensive flight test data taken using a variety of aircraft. This does not include the results

observed with the Velocity, which has the highest compression ratio (10.5:1) and therefore the best range observed among the modified aircraft, at 10% to 15% reduction in range. Figure 9 shows the decrease in range differential as compression ratio increases.

Experience has shown that in the Lycoming O-235 operating on ethanol at 2300 RPM and an EGT of 1350° F. results in a CHT of 375° F. and in an increase of 20 – 25 % consumption of fuel when compared to Avgas. This is well within the limiting operation temperatures established by Lycoming for this engine. Data compiled during flight training operations at the GAIFA are expected to confirm that operating at these engine temperatures will not only allow the engines to reach their Time Between Overhaul (TBO) of 2000 hours, but because of smoothness of operation and combustion characteristics unique to ethanol, the TBO will eventually be extended (as predicted by the FAA Designated Engineering Representative involved in the certification of the Lycoming IO- 540). With increased compression ratios and a better understanding of the safe temperature bounds for operating on Ethanol, it is anticipated that the differential in fuel consumption between Ethanol and Avgas can be considerably decreased.

The high octane of ethanol allows the use of higher compression ratio engines that deliver more power at the same throttle setting. The lower Vapor Pressure of ethanol helps prevent vapor lock. Ethanol burns cooler and cleaner than Avgas, and it is more resistant to detonation, resulting in lower vibrations and longer engine life.

Other key properties of the fuel were tested during the project. The FAA certification provided documented data supplementing the information previously obtained during flight tests. To obtain independent, authoritative characterizations, the

Fuels and Lubricants Research Division of Southwest Research Institute (SWRI) was engaged to conduct tests and data analysis on E-95.

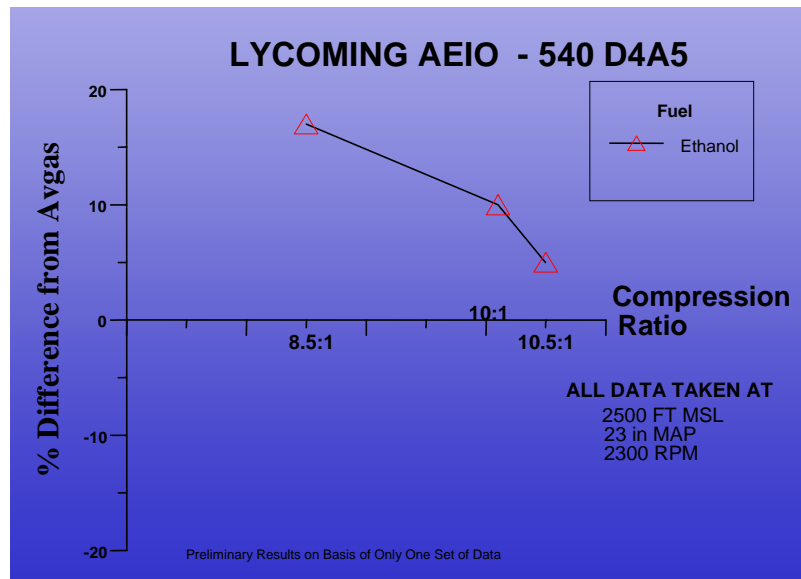


Figure 9. Difference in range between ethanol and Avgas with increasing compression ratio

#### *Modification of the Cessna 152*

The Cessna 152 was fitted with a bigger carburetor jet, a fuel pump, a fuel-flow meter and a totalizer. A small gas tank was added to prime the engine in temperatures below 65° F.

#### *Benefits to Local Economy and Local Communities*

The implementation of the GAIFA will be coordinated with the “Re-Birth of Hispaniola Project” (RHP) and the establishment of the biofuel industries on the island. In order to understand all of the implications of the synergy between these two programs and their close integration with the local community, a brief overview of the scopes and priorities of the RHP is herein presented.

### *The Rebirth of Hispaniola Project*

The goal of the “Re-Birth of Hispaniola Project” (Bros, RE-Birth of Hispanolia, 2005) is to create conditions on the island to spur economic growth and social development while improving the environment. The island of Hispaniola offers abundant natural resources but also huge environmental challenges, especially in Haiti where deforestation and soil erosion is widespread. Economic opportunities can be created through the development of sustainable agricultural practices that will provide products of high added value, mainly biofuels such as ethanol and Biodiesel. This will lead to the creation of employment in rural areas, alleviation of poverty and a decreased dependence on fossil fuels.

The implementation of these programs will be based on the principles of equitable development—ecological, economic, and human—seeking to create wealth through the investment of public and private capital in modern industrial technologies, in a manner that is in harmony with the principles of sustainable agriculture and the production of bio-energy.

The principle of equitable development vertically integrates all parties involved—private capital, biomass producers, and international investors—with the support and supervision of local government and international organizations maximizing the potential of sustainable bio-energy projects.

A Coordinating Commission team (CC) is being organized to administer and manage the RHP. The CC will have representatives from the government sector, private sector and international organizations. The private sector will design and implement the



programs, the government representative will provide support and supervision, and the international organizations will contribute technical and financial support.

The administration and supervision of the RHP will involve numerous governmental bureaus including the office of the Presidency of the DR and ministries such as Industry and Commerce, Environment, Export and Investment, Technical Secretariat of the Presidency -National Energy Commission, Agriculture and the Sugar Council (CEA) (Bros, 2005). The government representation will support the objectives of the program to reduce trade and national deficits while boosting exports through the marketing of quality and cost competitive products in the global marketplace. It will also assure political and financial support to the project some of which can be provided through carbon credits and others resources.

A Technical Center (TC), formed by representatives of the private sector will plan, manage and implement the project. It will also provide technical support in agricultural, industrial, marketing, administrative, and financial areas in particular to the small and medium size producers. These producers will be encouraged to join the “Associated Producers of Modern Biomass,” previously known as “sugar cane farmers-colonos.”

Projects to be developed in Haiti will be handled independently, although the CC structure will provide educational and technical support, in particular to the projects in the border region area. Here small producers’ projects that implicate high social impact responsibility will be prioritized and given preferential treatment.

The initial phase of the RHP involves the establishment of ethanol production from sugar cane and sweet sorghum, of Biodiesel from recycled oils and Jatropha

plantations, currently being planted, and the implementation of the Green Airport Program.

The RHP plans to invest \$318,000,000 USD in the Dominican Republic to plant 180,000 hectares of sugar cane and 60,000 hectares of sweet sorghum with an estimated total annual production of 245 million gallons of ethanol and 11 million tons of sugar cane. This would create 253,000 new jobs in the Dominican Republic and a Potential Electrical Co-generation of 212 MW.

The planting of oil producing plants such as *Jatropha Curcas* and *Pongamia Pinnata* for the production of bio-oils would involve the investment of \$120,000,000 USD. This program would support the reforestation of arid and eroded lands. The main goals of this program would involve planting 150,000 hectares of land with an annual production of 40 million gallons of oil and the creation of 75,000 new jobs.

Following this first phase, the focus of the program will be directed to the promotion of sustainable bioenergy communities and organic agriculture practices.

#### *The Contributions of the GAIFA*

The development of the Green Airport, included in the RHP first phase programs, is viewed as a very important aspect in the implementation of the broader plan. It will serve as a catalyst for the advancement of an energy policy on the island by promoting domestically produced renewable energy to meet growing energy demands. Government programs to blend ethanol in the general transportation fuels have already been approved in the DR.

The GAIFA will utilize the locally produced biofuels thereby contributing to the creation of quality jobs away from the city: professional and non-professional at the

airport, fuels production facilities and tourism sector jobs. Most importantly, it will provide demonstration and educational programs on the implementation of biofuels technologies and environmentally sustainable systems on the island. It is very important to develop these programs to educate not only the general public but also government officials, technical personnel and academic centers at all levels.

Aviation, which has always caught the public imagination, offers ideal opportunities to promote education on this topic. The knowledge gained in two decades of developing and implementing demonstration and educational activities all over the world will be the basis for educational programs at the Green Airport to help attract the general public and students of all academic levels to experience, first hand, the benefits of biofuels and renewable energy.

The implementation of the GAIFA will represent the first phase of the Green Airport. It will establish the base and the resources, both human and financial, to build the necessary systems and eventually the full-scale, off-the-grid airport.

In order to proceed in unison with the underlying philosophy of the broader program, it will be important to develop a business plan and structure for the GAIFA reflecting the principles of sustainable and equitable development of the RHP.

A group of students from the Business Excellence Scholarship Team (B.E.S.T.) 2005 class at the Baylor University Business School has developed, as a class project, a business plan for the flight academy. The plan provides a good base for the initial financial needs and projections. However, it needs to be tailored to the expanded scope of the program. The implementation of the GAIFA offers an opportunity to create a structure that would provide direct and tangible benefits to all of the people involved in

the program and the motivation to make it a success. A business plan is needed with an explicit financial structure that allows for an equitable distribution of profits from the business to all of the people involved in the program, according to role, effort and responsibility. This plan would involve an ownership structure, designed to provide long term interest, independence and security to all people involved; it would contribute to the creation of new business opportunities and social development in the area, providing a sustainable economic growth to the community. This plan would involve education and participation of the local community and would empower the people by providing livelihood opportunities and economic security while respecting environmental integrity, local traditions and cultural identities; emphasize equitable development consistent with the principles of transparency and accountability, respect for fundamental human rights and fair treatment of the workforce. The plan would also include a condition designating a certain percentage of profits to develop social structures and educational programs to benefit the local community.

The impending environmental crisis from climate change will very likely produce catastrophic events such as floods, droughts and fires, uprooting communities all over the globe. The most vulnerable people will be the poor of the world. The traditional development paths used by the industrialized nations cannot work any longer in developing countries that are simultaneously fighting environmental degradation and extreme poverty. New strategies are needed to implement effective, long term solutions with new patterns of investments that fund technological developments appropriate for local conditions and that involve a large percentage of the work force. This new approach would improve living conditions while promoting social responsibility and

sustainable development in these countries. A business plan for the Green Airport reflecting this vision is being developed.

### *The Full Scale Off-the-Grid Green Airport*

Once the GAIFA is established and running, efforts will shift focus to develop the full-scale, off-the grid, Green Airport program. The Green Airport will represent a model of environmental sustainability showcasing a mix of integrated renewable energy systems utilizing sun, wind, photovoltaic, biomass energy and biofuels, all readily available on the island (Zanin, Shauck, Alvarez, & Flynn, 2005). The Green Airport will create an international base for high visibility activities, including the world's first totally renewable energy powered center of excellence for pilot training, education and air quality monitoring. Parallel activities would include the establishment of a center for advanced development of ethanol in piston engine aircraft and research into the use of biofuels in turbine engines. Additional impetus to this initiative would be provided by the development of ecotourism activities at the airport served by aircraft powered by renewable fuels. A sustainable agricultural aviation program would also be developed and housed at the airport.

Locally, the Green Airport would be the base of a unique educational and demonstration program promoting the adoption of biofuels and renewable energy systems on the island and would be focused on creating a large number of quality jobs. In summary, the activities of the Green Airport will include:

- Flight Training (GAIFA) and academic courses coordinated with Dominican and international Universities, conferences, seminars, and short courses including professional and technical courses and seminars. Development of appropriate curriculum to integrate aviation and environmental topics to establish a scientist/pilot program

- Research on piston and turbines engines and certification programs of alternative fuels
- Eco-tourism activities and recreational flying using aircraft powered by locally produced biofuels
- The creation of a Sustainable Agricultural Aviation Center
- Establishment of an “in situ” GAW (Global Atmospheric Watch) station. The GAW represents the atmospheric chemistry component of the Global Climate Observing System (GCOS) and is part of the IGOS Project: “Integrated Global Atmospheric Chemistry Observations, (IGACO)”. (The proposal for the station has been approved by the D.R. Meteorological Centre and is currently being considered by the GAW)
- Air quality and environmental monitoring with instrumented aircraft to be performed in the Caribbean region and Central America
- Development of an inter-island Caribbean airline on renewable fuels

The contributions of the Green Airport program to the local community, the island of Hispaniola and the Caribbean region will include:

- Worldwide promotion and branding of a region where natural resources are valued and integrated with modern science and appropriate technologies to develop a model in the Caribbean area for environmental sustainability and human and social development
- Promotion of ecotourism activities in the Caribbean that will contribute to increase the attractiveness of the DR to tourists by demonstrating leadership in sustainable and renewable energy technologies and environmental enhancement
- Promotion of clean energy technology and environmental education for the country, the Caribbean and the world contributing to reduced dependence on fossil fuels by promoting energy efficiency and other renewable energy technologies—solar, wind, geothermal, hydro, bioenergy and renewable hydrogen
- An “Excellence in Aviation and Environment” Center that will provide educational and demonstration programs to local and international audiences

Once these activities are established, the emphasis will shift to the creation of the Renewable Energy Theme Park within the Green Airport.

#### *The Renewable Energy Theme Park*

The Airport and its infrastructure will become the core of the Renewable Energy Theme Park. New technologies and demonstration sites will be developed and diversified as the program grows and develops to showcase the feasibility of new renewable energy technologies. Energy independent buildings showcasing passive solar and photovoltaic systems will be added to house the academic programs and the students as well as a conference center for seminars on environmental sustainability.

Biofuels will be used for electricity generation using, for example, locally produced Biodiesel from Jatropha; all of the systems and building will eventually be powered by solar, photovoltaic and wind energy. A Caribbean Institute for Renewable Energy and Information Technologies will be developed at the Renewable Energy Theme Park to overview activities and to assure the adoption and maintenance of the best technologies and the promotion of renewable energy projects around the region through education and demonstrations. Research and educational activities, including academic courses integrating current results, will be promoted to universities, institutes and organizations around the world through distance learning courses and on site programs.

Internationally, the growing concerns associated with the environmental impact of aviation and the challenges represented by the threat of global warming underscore the importance and timing of this project. Once the concept of the Green Airport is proven locally, expansion of the program to the other airports on the island and other islands in the Caribbean will follow.

Eventually, this experience will be showcased as a model of an integrated Green Airport concept, promoting sustainable aviation, to be replicated throughout the world and adapted to local conditions. The next step in promoting the Green Airport concept will be a flight around the world with aircraft powered by biofuels.



## CHAPTER FIVE

### Conclusions and Recommendations

Currently, there are no easy solutions to significantly and effectively reduce emissions caused by aviation. Aviation is an essential mode of transportation for an ever increasing number of passengers and goods due to the demand for the most efficient and cost effective manner of traveling in increasingly global economies and cultures.

Aviation has facilitated connections to remote areas in the world and provided emergency assistance in critical situations. It has promoted tourism in secluded areas bringing vital improvements in the quality of life of isolated populations. Aviation has been a significant source of employment and growth in many regions of the world. Enormous economic progress and cultural exchange across the globe have been made possible by aviation which holds even greater promise to further level the considerable economic imbalances in the world.

For these, and many more reasons, the aviation industry is globally essential. However, its negative environmental impacts must be recognized. Only the implementation of a multi-faceted anti-pollution approach, in parallel with ongoing research in this area, can alleviate its negative environmental impacts. Measures will have to address the impact of emissions at different levels and conditions:

- a. At the local level, the impact of toxic emissions in and around airports, produced by aircraft taxiing, taking-off and landing in the proximity of airports, and by the ground based airport traffic, i.e. ground equipment at airports and vehicle traffic;
- b. At the regional level pollution caused by aircraft approaching and leaving airports or flying low, and;

- c. At the global level, pollution caused by emissions released at high altitudes, which are the most damaging in terms of exacerbating climate change.

The aviation industry must improve its environmental record. Innovative technologies and cleaner fuels are available; biofuels are already economically competitive and can provide adequate, or even superior, performance when compared to the current fossil fuels. Developing bio-based fuels for the aviation industry, in the face of mounting environmental pressures and rising fossil fuel prices, is a significant way to improve the current situation. Favorable conditions to foster such a change include:

- Growing concern over climate change due to rising greenhouse gas emissions
- Favorable legislation in the energy and transportation sectors
- The mounting price of aviation fuels
- Nearly three decades of experience in developing and advancing biofuels technologies

Seeing as there are no insurmountable technical obstacles and aviation is in urgent need of a clean alternative fuel, one may ask: “What has prevented this from happening?”

Over the last three decades, the Renewable Aviation Fuels Development Center (RAFDC) and the Baylor Institute for Air Science (BIAS) at Baylor University have led the world in advancing biofuels in aviation. Much progress and development has occurred since the inception of the programs, but much more is needed. During these years, the author and BIAS colleagues have attempted numerous strategies to find the right formula to spark the interest of the aviation community in alternative fuels and the adoption of sustainable practices. The “Green Airport” and the implementation of the Green Airport International Flight Academy (GAIFA) in the Dominican Republic (DR) represent the latest effort to provide a simple model that can demonstrate the feasibility

and the advantages of biofuels and renewable energy in aviation; a model that can eventually be reproduced anywhere in the world.

The research, development and testing performed at the RAFDC/BIAS have proven the feasibility and the environmental compatibility of biofuels in aviation for both the piston and the turbine engine aviation fleets. Biofuels are the most rapidly growing transportation fuels in the world and their adoption makes great sense in general aviation.

Blends of Biodiesel up to 20% have been tested in flight in turbine engines since the late 1990's. The first flight on 100% Biodiesel took place (October 2007) in Nevada in a L-29 military jet aircraft. The aircraft is currently being prepared to make a first cross country flight from Nevada to Florida on 100% Biodiesel. Other types of biofuels are being tested for the turbine engine fleet that would satisfy the chemical and physical characteristics required by the commercial and military jet fuel specifications.

Worldwide crop availability and production costs, in addition to technical suitability, will be considered to assess the viability of these new biofuels.

Ethanol and other biofuels are truly the transition fuels for spark and compression ignition engines. Ethanol can be produced locally from renewable resources. It augments starch and sugar feedstocks, including waste streams, with cellulosic biomass.

Ethanol is the best currently available candidate fuel to replace Avgas for the following reasons:

1. Ethanol is now considerably cheaper than 100 octane low-lead aviation gasoline
2. Ethanol can be produced locally from renewable resources
3. Ethanol is a superior aviation fuel for piston engines possessing higher detonation resistance and other technical advantages over aviation gasoline

4. There is considerable market potential for ethanol in aviation in the US and the world
5. EPA is seeking ways to phase out lead in Avgas
6. The threat of climate change is altering the interrelationships between national energy security, economics and environment. Transitioning from fossil to biofuels in aviation scores on all these issues embracing the concept of advanced cleaner technologies to handle climate change issues.

Rigorous certification procedures for engines and aircraft, administered by the Federal Aviation Administration (FAA), were successfully completed utilizing 100% denatured ethanol. One aircraft series certified on ethanol is the Cessna 152, the most popular training aircraft in the world. This aircraft type has been chosen to form the first fleet of training aircraft at the GAIFA in the DR. The motivation to implement this program has been provided by the urgency to demonstrate the feasibility of biofuels on a noticeably large scale commercial operation where the economic benefits and the technical advantages of biofuels will be tangible and irrefutable.

The DR was chosen as the site of the first Green Airport due its ideal conditions that include:

- Abundant biomass and renewable energy resources
- Developed tourism and aviation infrastructures
- Opportunity to benefit the environmental, social, economic and political circumstances of both countries, the DR and Haiti, by the establishment of a biofuel and renewable energy industry
- Easy access for tourists from North, Central, South America and Europe through regularly scheduled flights

The use of ethanol at the GAIFA will provide several benefits

- Savings in fuel costs and maintenance of aircraft
- Cleaner emissions

- Reduction of CO<sub>2</sub> emitted in the atmosphere
- Increase in engine power developed—with a slight reduction in range as the only drawback

The GAIFA will support the objectives of a national strategic energy program to gradually meet energy demands by adopting sustainable energy practices. It will promote:

- Improved economic conditions and quality of life in the countryside where the crops are planted and the fuel produced
- Creation of new jobs at the airport and through secondary services
- Educational and demonstration programs, both at the local, regional and global level
- Implementation of renewable energy systems and improved environmental practices
- Opportunities to utilize aviation to expand the eco-tourism concept and activities
- Sustainable agricultural practices and education in this field supported by agricultural spray aircraft powered by biofuels
- On going research, certification and further implementation of biofuels in aviation, ground equipment and ground transportation
- The implementation of a business model that will promote equitable and sustainable development through opportunities for agricultural growth and incentives that would establish enterprises in rural areas (such as biofuel production) resulting in the development of social infrastructures in the countryside

The scope of the GAIFA in the DR is to demonstrate the reliability of high-performance, clean burning, renewable fuels for aircraft engines by training pilots and scientist/pilots with aircraft powered by biofuels. Educational programs and renewable energy systems will be gradually integrated and added to provide further learning opportunities and demonstration programs in a highly cost effective and sustainable

manner. The end result, the Green Airport and the Renewable Energy Theme Park, will be showcased locally, regionally and internationally to provide a unique educational experience and a model to be replicated regionally and eventually worldwide.

The threat to the environment, as a result of fossil fuel use, coupled with the threat to national security as a result of the nations' increasing energy dependence, can no longer be ignored. The potential of biofuels to benefit energy and national security, to improve the quality of the environment, and to provide quality jobs and sustainability to local communities alleviating emigration to the cities or to other countries is enormous. We have only begun to realize the benefits that could accrue from the adoption of renewable, clean-burning, domestically produced aviation fuels.

### *Recommendations*

Before embarking on the implementation of this project it is vital to objectively review the lessons learned and the roadblocks encountered in nearly three decades of intensive work in this field. Following are a few recommendations to consider in the implementation of this new concept:

#### *1. Sufficient resources*

In order to implement effective programs adequate resources are critical. The accomplishments and successes of past programs were results of enormous expenditure of personal time and physical effort coupled with unlimited enthusiasm and dedication. Limited human and financial resources can only result in limited outcomes. Adequate resources are essential to promote the implementation of biofuels in aviation on a significant scale. Resources are needed to:

- a. *Promote educational programs.* Lack of information on biofuels and renewable energy resources among the general public is a major obstacle to implementation. The misinformation disseminated by those interested in keeping the world captive to fossil fuels is preventing the general public from learning basic information about the technical economical and environmental benefits derived from biofuels. Education about biofuels would bring about a major change in the attitude of the consumers.
- b. *Proceed with certification programs.* Certification of engines and airframe on biofuels can be carried forward on a continuing basis while implementation and pilot projects are spreading.
- c. *Further research into improving the efficiency of engines.* This research can also be pursued in parallel to educational and certification activities. Emission testing of aviation engines is critical; new aviation fuels will have to be clean, renewable, and domestically produced.
- d. *Implement an adequate large-scale, high visibility project.* Sufficient initial resources are critical to implement a program on a scale adequate to maximize its visibility and its potential to showcase technologies and educate a large audience in order to make a substantial impact.

## 2. *Concerted effort and commitment*

The main problem in the past has been sporadic support to advance biofuels and sustainability in aviation due to changing administrations and shifts in priorities of federal agencies and organizations. A concerted effort could considerably support and expedite the implementation phase of biofuels in aviation. Commitment to implement biofuel programs is critical from:

- a. *State and federal agencies, governmental and non –governmental national and international organizations.* These organizations should have a high interest and consequently a more active role in supporting the establishment of decentralized biofuel industries, especially those being proposed in developing countries. Solid commitments from these agencies, brought together in a coordinated manner to implement an effective biofuel program, would expedite the adoption of biofuels in aviation providing opportunities to establish biofuel distribution networks that would benefit the economy and the environment
- b. *National agricultural agencies, organizations and private agri-business sector.* The benefits that would accrue to the farming community if biofuels were to be widely adopted are obvious. Coordination among national and state agricultural

agencies and organizations and the agri-business private sector would be highly advantageous for the creation of decentralized production facilities, refueling infrastructures and distribution systems for biofuels including airports. Improvement of life quality in rural communities worldwide would alleviate the problem of immigration to the cities or to other countries while contributing to improve energy and national securities.

- c. *Biofuel producers, distributors and related industries.* The ethanol industry, now in a strong position, has until recently been mostly concerned with its own survival and has been, at best, inconsistent in its commercialization strategies and plans for the future. Some might perceive ethanol as an aviation fuel as an exotic idea. Consistent support, commitment and trust from the industry are critical to move the implementation of this program forward. Logistical problems can be easily resolved with the support of the existing industry, especially with greater fuel availability worldwide.

### 3. *Overcome aviation industry conservatism and power of the petroleum industry*

Inherent in the nature of aviation is an understandably high degree of safety awareness and risk aversion. This has been the cause of often extremely conservative attitudes in the commercial aviation industry, particularly when it comes to adopting new technologies. Obviously, an element of risk is always introduced in the testing phase of a new technology in aviation, particularly a new fuel. However, the risk phase of ethanol development has long since ended. Ethanol has been subjected to intense scrutiny by the FAA, aviation industry, and, in particular, the petroleum industry, mainly because it is a new fuel competing with a well established one. The same is true for bio-based fuels for the turbine engine fleet. Although more research and testing needs to be conducted in order to identify the best feedstocks and technologies to produce cleaner and economically efficient fuels, the degree of risk is minuscule, especially when compared to the impending threat of a global climate change.

A de facto alliance between many sectors of the aviation industry, federal agencies, politicians and the petroleum industry has taken place over time. While this is



to be expected, given the requirements of close cooperation between these groups, it has led to a situation and power structure that favors the use of established technologies that would otherwise not be able to compete in the current circumstances. More specifically, if aviation gasoline and ethanol were both new fuels, given no preference on either side due to power alliances, political and commercial contributions and the myriad of other entanglements, there would be no contest between the two fuels; ethanol would easily prevail. Ethanol outperforms aviation gasoline, is more economical, far better for the environment, especially if produced in a sustainable manner, and is renewable and domestically produced.

One of the very difficult obstacles to overcome is the strong influence the petroleum industry wields on the media. Again, this influence as demonstrated by the large revenues various media receive as advertising fees from the petroleum industry. It is only mentioned in this context to help understand the difficulties encountered in adopting ethanol, or for that matter, any non-petroleum fuel, as a commercial aviation fuel. Widespread distribution of accurate and reliable information is essential. This can be attained by:

- *Establishing a worldwide information and technology transfer network through the Internet.* The World Wide Web is the best tool to provide rapid access to factual information and help displace long standing misinformation over biofuels while promoting their advantages. The expectation is that once the model of the GAIFA and the “Green Airport” is established, people from around the world will have access through the internet to the knowledge and the experience accumulated on the advantages of biofuels, renewable energy and their applications in aviation. The internet can also provide the vehicle, through distance learning, to teach courses and to showcase systems helping to replicate the model in other countries
- *Coordination among local and international organizations.* It will be essential to involve as early as the planning phase local organizations and communities while engaging international parties and foreign organizations to

participate in the development of the model by contributing to innovative technologies and also by supporting the dissemination of information and technology around the world

- *Rapidly proving the economical viability and the environmental compatibility of the Green Airport model.* Nothing will be more convincing to the aviation industry and the aviation community than showcasing a working model. The idea is to produce a model structured according to a simple modular formula to allow its adaptation to a range of circumstances, needs and conditions. It will be vital to proceed boldly while maintaining adaptive flexibility
- *Producing a roadmap to facilitate technology transfer.* The preparation of very simple and clear informational documents with procedures extending from the basic operations to the full-scale model of the Green Airport will be a priority. Information and procedures would also be integrated and extended gradually to secondary activities such as production of fuels and external services provided to the airport in order to describe the model's economical and social benefits to the local communities
- *Embarking in a worldwide educational /demonstration tour.* This would provide the best educational experience to audiences worldwide. This will be the mission of the "Spirit of Hispaniola" flight around the world

### *The Spirit of Hispaniola Flight around the World*

The "Spirit of Hispaniola" aircraft (the "spirit" does not just refer to the ethanol but to the endeavor) will be powered by biofuels and instrumented for air pollution monitoring. Two aircraft will be involved; one piston engine aircraft powered by ethanol and one turbine engine aircraft powered by Biodiesel.

The proposal is to convert the aircraft to biofuels, equipping them with "cutting edge", high technology instrumentation to monitor air pollution throughout the flight in association with a live, "state of the art", educational program promoting the replication of the Green Airport program. This would be an educational/demonstration flight with many stops in as many countries as possible to promote biofuels, the Green Airport model, air quality education and the advance of sustainability through energy efficiency

and renewable energy technologies. It will be organized in coordination with government organizations, NGOs, universities and schools of all levels, environmental organizations, foundations and private organizations interested in providing support to this program. It will seek high media exposure to maximize its worldwide impact.

The aircraft will house an airborne laboratory to monitor air quality to be used in live teaching sessions scheduled and broadcasted in collaboration with universities, institutes and governmental organizations worldwide, to provide educational programs on air pollution dynamics, monitoring and analyses and the relationship of air quality with fossil fuels combustion. The benefits of biofuels and renewable energy sources provide extensive material for lectures. Although the goal of this undertaking will be education, it will also provide the opportunity to begin a process of technology transfer of low-cost proven technologies and systems to monitor air quality and to implement renewable energy programs.

People from various parts of the world with expertise in appropriate areas of renewable energy will participate in the flight for selected legs of the trip to support the educational part of the program and add local participation to the mission. Another aspect of the flight will involve students from all countries where the aircraft lands. Before the flight takes place, students from each country will compete for an environmental project design of their own for an “award” consisting of being a passenger, or co-pilot, for a certain leg of the flight. The winner would personally deliver the winning project as a contribution to the next country visited.

Many other projects can be integrated into this program in order to actively involve students and audiences from all over the world. Foundations, government and private organizations will be solicited to support the flight.

The main goal of this flight will be educational. It will be a highly visible and effective tool for all levels of academic and public education about air pollution, renewable energy and alternative fuels issues. Informational material will be produced and distributed on an on-going basis throughout the flight, and it will be tailored to inform and educate all educational levels, besides the general public and appropriate government representatives.

The flight will provide an exciting medium to educate people all over the world, especially in developing countries where there are fewer opportunities to be exposed to similar programs, on the benefits of renewable energy, biofuels and air quality problems related to fossil fuel combustion. To reach the largest possible audience, the project will employ in-flight and ground-based distance learning broadcasting to students and scientists in countries around the world. One of the objectives will be to develop a series of lectures designed to educate the general public about air pollution and the basic science necessary to understand the nature of the problem and the possible solutions.

Broadcasts from the aircraft will include graphic representation of real time pollution levels as they are measured in specific geographical areas during an air quality monitoring mission. The instrument operator will describe and explain the graphic representations while utilizing the instrument signals to direct the flight path of the aircraft. The data collected by the aircraft would be readily available and it could be routinely reported live by the media in each country.

An additional benefit of the flight will be its contribution to our understanding of air quality and long-range transport of pollution in regions of the world where there is little or no information of this type, while providing a demonstration and the “know how” of air pollution monitoring with aircraft to countries unfamiliar with this investigative tool. This program would also help establish a global air sampling network. Specific training sessions to teach all phases of aircraft air sampling would be developed, including aircraft instrumentation and modification, instrumentation function, air pollution operational training for pilots and instruments operators, data handling, validation and analyses. A small low cost instrumented aircraft, being developed for the last decade at BIAS as an air quality monitoring platform, could be offered to countries in need of such monitoring as a follow up to this program (Zanin, Shauck, Alvarez, & Buhr, 2002). The goal would be to create a network of small, low-cost air sampling aircraft equipped with technologically advanced air pollution monitoring instrumentation. This affordable tool could be adopted by State agencies, large and even medium-sized municipalities, and many other organizations responsible for air quality hitherto unable to afford the critically important information provided by aircraft sampling. This will lead to a considerable increase in the quantity and quality of air pollution data available. The expanded information base would then be readily available to local, state, federal government agencies and world organizations to guide elected representatives in their decisions concerning air quality control and strategies.

To conclude, the objective of the flight will be to advance an exciting new way to educate the public about increasingly critical scientific issues that are essential in order to coordinate efforts among the countries so that each takes its own portion of responsibility

for the housekeeping practices of our planet. A successful outcome will have enormously far reaching implications on the advancement of the public knowledge about air quality issues, on the environmental degradation caused by fossil fuel combustion and on renewable energy and cleaner fuels technologies.

In each country the aircraft lands, exhibits will be organized on the overall concept of “bio-sustainability”. The exhibits will include information on the environment, air quality, biofuel and renewable energy showcasing the Green Airport concept as a model. Handicrafts produced by communities in the DR with natural local products could help explain simple concepts and provide models to showcase and leave in each country. The exhibits would describe all of the ongoing activities at the Green Airport and provide the knowledge and support to replicate the model from production and utilization of biofuels to ecotourism activities and educational programs.

The flight of the “Spirit of Hispaniola” will be launched from the island where Christopher Columbus landed over 500 years ago and began the first phase of globalization. Although this time around, the circumnavigation of the “Spirit of Hispaniola” will symbolize an enlightened rebirth of Christopher Columbus’s vision with a focus on ensuring the sustainable and environmentally sound advance of all societies. This vision and message will travel around the world to plant in each country the seeds of new opportunities; economic models that equitably employ biofuels and renewable energy to create new industries, businesses and new jobs that will improve living conditions, promote sustainability and help eradicate poverty.

The “Spirit of Hispaniola” will spread the message of a new paradigm for globalization, one that promotes energy efficient exchange of ideas, concepts, knowledge

and technology, and minimizes energy intensive trade of fuels, foods and goods all over the globe. The motto will be: “produce locally and respect the global environment”.

Above all, “do more with less”, as Dr. Paul MacCready would say.

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