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TRINIDAD AND TOBAGO

FEASIBILITY STUDY ON THE USE OF SUSTAINABLE AVIATION FUELS

ICAO-EUROPEAN UNION ASSISTANCE PROJECT: CAPACITY BUILDING FOR CO_2 MITIGATION FROM INTERNATIONAL AVIATION

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EXECUTIVE SUMMARY

The International Civil Aviation Organization is a United Nations agency working together with its 192 Member States and industry groups to reach consensus on international civil aviation Standards and Recommended Practices and policies in support of a safe, efficient, secure, economically sustainable, and environmentally responsible international civil aviation sector.

In its efforts to help reduce carbon dioxide emissions, the International Civil Aviation Organization has developed partnerships with international organizations and states to develop assistance projects and promote a basket of measures designed to support Member States as they work to achieve the global aspirational goals. These goals, adopted by the 37th Session of the Assembly in 2010, seek to improve fuel efficiency by 2 per cent per year from 2020 and to keep net carbon dioxide emissions at the same levels (i.e. carbon neutral growth from 2020).

The International Civil Aviation Organization - European Union assistance project on Capacity Building for CO_2 Mitigation from International Aviation is the first International Civil Aviation Organization's assistance project on environmental issues that provides selected Member States guidance and training to develop action plans on carbon dioxide emissions reductions, a robust and fully operating carbon dioxide monitoring system, and assistance for the successful implementation of mitigation measures, including the coordination of stakeholders, preparation of feasibility studies, and facilitation to access financial resources through partnerships with interested parties. Trinidad and Tobago is one of 14 Members States from Africa and the Caribbean selected to participate in this assistance project.

In an effort to contribute towards the International Civil Aviation Organization's aspirational goals, Trinidad and Tobago developed an Action Plan for Carbon Dioxide Emissions Reduction for Trinidad and Tobago and the Piarco FIR. The following feasibility study is a result of the International Civil Aviation Organization's support for Trinidad and Tobago's determination to contribute towards the sustainable development of its aviation sector, specifically assessing the use of sustainable aviation fuels and sustainable fuels for ground support equipment, as a viable option to reduce emissions. This study, conducted from July 2016 to March 2017, was developed and financed under the International Civil Aviation Organization – European Union project framework and involved more than 30 relevant stakeholders from the government, industry and academia.

The aviation sector's focus is on "drop-in" fuels, a substitute for conventional jet fuel that is completely interchangeable and compatible with conventional jet fuel. A drop-in neat fuel does not require adaptation of the aircraft/engine fuel system or the fuel distribution network, and can be used "as-is" on currently flying turbine-powered aircraft in pure form and/or blended in any amount with other drop-in neat, drop-in blend, or conventional jet fuels. Currently, there are five conversion processes that can transform biomass into drop-in alternative aviation fuels approved for use as blends on turbine engines: Fischer-Tropsch Synthetic Paraffinic Kerosene, Fischer-Tropsch with aromatics, Hydroprocessed Esters and Fatty Acids, Synthetic Iso-Paraffins, and Alcohol to Jet. Both Fischer-Tropsch classes and Hydroprocessed Esters and Fatty Acids fuels have been approved for use in blends at up to 50 per cent by volume with conventional jet fuel, while Synthetic Iso-Paraffins and Alcohol-to-Jet fuel can only be blended at up to 10 and 30 per cent respectively.

This report evaluates several feedstocks available in Trinidad and Tobago for the production and use of approved sustainable aviation fuels including agricultural products, algae, waste gases from petrochemical production, and municipal solid waste. After careful analysis, findings reveal that under current conditions, the lack of a level playing field in commercial markets as well as the lack of quantity and quality of locally sourced sustainable feedstock makes the deployment of sustainable aviation fuels in Trinidad and Tobago economically unviable.

At present time, the various national policy frameworks to promote the development of sustainable aviation fuels are causing distortions in market access as countries are able to regulate the commercialization of sustainable aviation fuels through local policy (subsidies, tax exemptions, etc.) resulting in unfair price competitiveness among global producers. In addition, sustainable aviation fuels are currently priced higher than conventional jet fuels, making them unable to compete. Given a potential future scenario when sustainable aviation fuels are regulated through global policy, prices are set by market forces, and emissions from aviation are given a monetary value, Trinidad and Tobago may find new opportunities allowing it to become a viable player in the industry of sustainable aviation fuels. Of primary interest to Trinidad and Tobago would be the future development of a biomass-to-liquid plant using Fischer-Tropsch technology for the conversion of biomass to liquid sustainable aviation fuels produced from renewable resources like municipal solid waste, and agricultural and forest residues. This will require significant investment in the incorporation of advanced waste management infrastructure on current landfills capable of efficiently capturing methane for use as a renewable, sustainable feedstock for conversion into biomass to liquid sustainable aviation fuels.

There are three main reasons why biomass-to-liquid Fischer-Tropsch fuels are most suitable for Trinidad and Tobago for processing into sustainable aviation fuels in comparison to other sustainable aviation fuels pathways for conversion into aviation fuels:

- Waste biomass is usually less expensive than other approved feedstocks for sustainable aviation fuels production, like virgin vegetable oils and waste oils.
- Waste management currently represents an increasing cost to the Government of Trinidad and Tobago (primarily municipal solid waste) and its use as feedstock for conversion into sustainable aviation fuels will transform it into a valued resource.
- The current construction of a gas-to-liquids Fischer-Tropsch plant in Pointe-A-Pierre will provide Trinidad and Tobago with a significant comparative advantage over foreign competitors by being able to immediately employ a skilled workforce in Fischer-Tropsch technology and rely on an already established functional supply chain for the fast and effective deployment of sustainable aviation fuels. Gas-to-liquid fuels from fossil energy sources do not qualify as renewable or sustainable, yet the government's support today to ensure the healthy and efficient development of this new industry can help pave the way for Trinidad and Tobago to become competitive in future markets for sustainable aviation fuels.

The study also considers the potential to reduce carbon dioxide emissions from the aviation sector by evaluating sustainable fuels to power ground support equipment. There are approximately 95 ground support equipment vehicles (28 gasoline and 67 diesel powered vehicles) operating on Trinidad and Tobago's airport grounds. The small size of this vehicle fleet is a significant limiting factor for the economic viability of most processing plants for the production of sustainable aviation fuels like ethanol or drop-in biodiesel. Yet, two alternative fuel options were identified as suitable to help reduce current carbon dioxide emissions from ground support equipment within the next two to ten years:

- The use of a blend mix of biodiesel processed from used cooking oil to power diesel powered vehicles. A 30 per cent blend mix can result in a reduction in carbon dioxide emissions of approximately 739,563 kg/yr from ground support equipment. The study presents a pilot case where a small scale processor, the FuelPod4, is used to provide a blend mix of 7.6 per cent biodiesel from used cooking oil to power ground support equipment at PIARCO International Airport. The used cooking oil is collected from nearby restaurants and hotels, an initiative that was already partially studied by the University of West Indies. Pending satisfactory results from the pilot case, the project can then be escalated to increase the percentage of biodiesel present in the blend mix and extend from ground support equipment vehicles to shuttle buses on university campuses and other symbolic vehicles.
- The use of compressed natural gas as a substitute for gasoline powered ground support equipment vehicles. The set-up of two mobile compressed natural gas charging stations in the north and south terminals of PIARCO International Airport can supply ground support equipment with a cleaner burning fuel. Though compressed natural gas is not a renewable or sustainable fuel, the replacement or retrofit of all gasoline ground support equipment vehicles at PIARCO International Airport could help reduce carbon dioxide emissions by approximately 21,835 kg/yr. This proposal also serves to further support the current efforts by the Government of Trinidad and Tobago to increase the use of compressed natural gas for land transport applications.

At the pilot stage, even though both options are economically viable, resulting environmental benefits remain small mostly due to the limited size of the ground support equipment fleet. Yet, in the case of biodiesel, once the process of used cooking oil conversion into biodiesel is streamlined and runs efficiently, the initiative can be extended to public transport and college shuttle services. Environmental benefits will then become more significant and include the reduction in the impact on local air quality and human health. In addition, the government of Trinidad and Tobago can use these projects to add to the campaigns to raise awareness of its commitment to environmental protection, and on the need for the community to become involved and partake in the effort to care for their health and the preservation of natural resources. Trinidad and Tobago can become an example in the Caribbean region for others to follow, demonstrating their strong commitment to environmental protection. It also serves to help comply with the Government of Trinidad and Tobago's Intended Nationally Determined Contributions declared under the United Nations Framework Convention on Climate Change to reduce carbon dioxide emissions from the transport sector.

In the long term, the most environmentally friendly option to reduce carbon dioxide emissions from ground support equipment is to replace the vehicle fleet with electric vehicles powered by solar energy. The terms of reference to conduct a comprehensive feasibility study for the installation of a solar farm on airport grounds at PIARCO International Airport has already been presented by the Airport Authority of Trinidad and Tobago to be funded by the International Civil Aviation Organization – European Union Project. This solar farm could supply most of the energy needs for airport operations as well as incorporate clean energy to the national grid for use for residential, commercial and industrial purposes.

Limited availability of the right quantity and quality of natural resources for processing into sustainable aviation fuels as well as current high production costs of sustainable aviation fuels compared to conventional jet fuel restricts short and medium terms options Trinidad and Tobago can take to significantly reduce carbon dioxide emissions from the aviation sector. Furthermore, unlike the market for fossil fuels, the market for sustainable aviation fuels can be heavily influenced by countries enacting policies for the commercialization of sustainable aviation fuels favouring local producers. Nevertheless, future developments may alter these scenarios to more favourable conditions allowing Trinidad and Tobago to become a competitive player in the supply of sustainable aviation fuels. In the long term, the government can make significant strides in reducing carbon dioxide emissions from ground support equipment by installing a solar farm and requiring ground support equipment providers to replace their vehicle fleet to electric vehicles. These actions will need the support of new targeted policies to ensure long term success as well as commercial security to potential investors.

CONTENTS

ABBREVIATIONS AND ACRONYMS

AES - Aviation Environmental Systems
AEWG - Aviation Environmental Working Group
AFTF - Alternative Fuels Task Force
APER - Action Plan on Emissions Reduction
APERTT - Action Plan for CO_2 Emissions Reduction for Trinidad and Tobago and the Piarco FIR
BTL-SAF - Biomass-to-Liquid Sustainable Aviation Fuel
CAEP - Committee on Aviation Environmental Protection
CAPEX - Capital Expenditure
CARB - The California Air Resources Board
CH4 - Methane
CNG - Compressed Natural Gas
CO - Carbon Monoxide
CO_2- Carbon Dioxide
dLUC - Direct Land Use Change
EV - Electric Vehicle
GDP- Gross Domestic Product
GHG- Greenhouse Gases
GORTT - Government of the Republic of Trinidad and Tobago
GSE - Ground Support Equipment
H_2 - Hydrogen
H_2O - Water
ICAO - International Civil Aviation Organization
IFSET - ICAO Fuel Savings Estimation Tool
iLUC - Indirect Land Use Change
INDCs - Intended Nationally Determined Contributions
JIG - Joint Inspection Group
LCA - Life-Cycle Analysis
LFG - Landfill Gas
LUC - Land Use Change
MALF - Ministry of Agriculture, Land and Fisheries
MEEI - Ministry of Energy and Energy Industries
MFPLMA - Ministry of Food Production, Land and Marine Affairs
MPD - Ministry of Planning and Development
MSW - Municipal Solid Waste
N_2 - Nitrogen
NETL - NiQuan Energy Trinidad Limited
NGV - Natural Gas Vehicles
NO_X - Oxides of Nitrogen
NP - National Petroleum Company
PAS - Piarco Air Services Limited
PETROTRIN - Petroleum Company of Trinidad and Tobago Limited
RFS - Renewable Fuel Standard Program
RINs - Renewable Identification Numbers
SAF - Sustainable Alternative Fuel
SARPs - Standards and Recommended Practices
SOX - Oxides of Sulfur
SWGTT2 - Specific Working Groups for Trinidad and Tobago on Alternative Fuels
SWMCOL - Trinidad and Tobago Solid Waste Management Company
TT$ - Trinidadian Dollar
TTCAA - Trinidad and Tobago Civil Aviation Authority
U.S. - United States of America
U.S. EPA - United States Environmental Protection Agency
UCO - Used Cooking Oil
WTE - Waste-to-Energy

UNITS

bbl - Oil Barrel
BCF - Billion Cubic Feet
bpd - Oil Barrel per Day
bpyr - Oil Barrels Per Year
CO_2e - Carbon Dioxide Equivalency
ft^3- Cubic Foot/Feet

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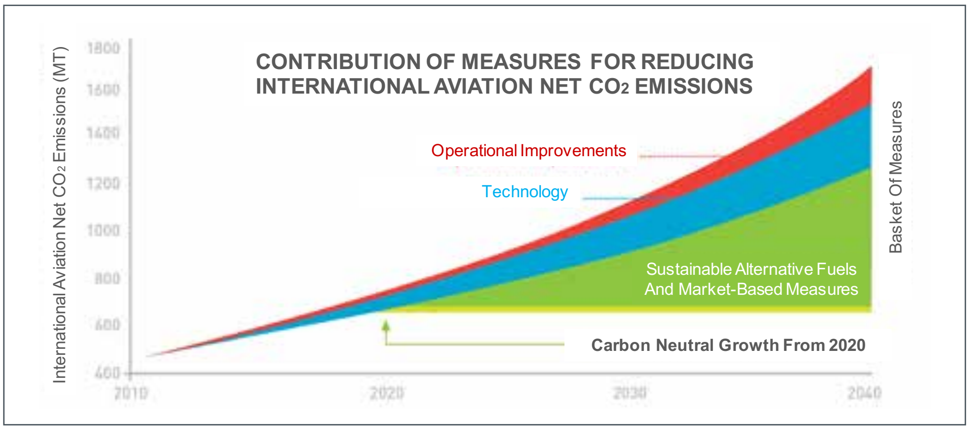
1. INTRODUCTION

International aviation emissions currently account for 1.3 per cent of total global anthropogenic carbon dioxide (CO_2) emissions, and this is projected to increase as a result of the continued growth of air transport. ICAO and its Member States recognize the critical importance of providing continuous leadership in order to limit or reduce emissions that contribute to global climate change. The ICAO 39th Assembly reiterated the global aspirational goals for the international aviation sector of improving fuel efficiency by 2 per cent per annum and keeping the net carbon emissions from 2020 onward at the same level, as established at the 37th Assembly in 2010. The Assembly also recognized the work being undertaken to explore a long-term global aspirational goal for international aviation in light of the 2°C and 1.5°C temperature goals of the Paris Agreement and more ambitious goals are needed to deliver a sustainable path for aviation as the aspirational goal of 2 per cent annual fuel efficiency improvement is unlikely to deliver the level of reduction necessary to stabilize and then reduce aviation's emissions contribution to climate change.

To achieve international aviation's global aspirational goals, as shown in Figure 1, a comprehensive approach is necessary, consisting of a basket of measures including technology and standards, sustainable aviation fuels (SAFs), operational improvements and market-based measures to reduce emissions.

FIGURE 1
Contribution of measures for reducing international aviation net CO_2 emissions[1].



Mitigating the release of CO_2 emissions into the atmosphere is the main incentive for promoting the use and deployment of SAFs in aviation. CO_2 is emitted from the combustion of SAFs; however, this carbon came from plants and then will be absorbed by newly-growing plants in a closed loop. Since that CO_2 is re-absorbed, SAF provides an environmental benefit over the full product life-cycle, as compared to the production and combustion of conventional jet fuel. Depending on the SAF pathway, SAF can provide up to an 80 per cent reduction in emissions compared to conventional jet fuel.

Beyond CO_2 emissions reductions, there could also be additional benefits, such as promoting new domestic industries and production systems, improving the competitiveness of the aviation and tourism sectors in the State over the long-term, and improving the local air quality by decreasing the particulate matter (PM)[2] emitted by aircraft[3].

[1] ICAO Environment: GFAAF - Aviation Alternative Fuel Live Feed. Retrieved from https://www.icao.int/environmental-protection/GFAAF/Pages/default.aspx

[2] At the engine exhaust, particulate emissions mainly consist of ultrafine soot or black carbon emissions. Ultrafine particulate matter (PM) emissions are known to adversely impact both health and climate (ICAO. Environmental Report: Aviation and Climate Change. Retrieved from https://www.icao.int/environmental-protection/Documents/ICAO%20Environmental%20Report%202016.pdf

[3] S. Christie, 2016. Emissions report and database of systems key performance parameters. s.l.: D4.9 ITAKA project.

With the interconnection between energy and sustainable development, bioenergy[4] is a prime example of how energy can link with other areas, including water quality and availability, ecosystems, public health, food security, and education and livelihoods, and can harness multiple benefits, insofar as the development is properly planned and managed. Through the use of alternative fuels for transportation and bioelectricity, the development of sustainable and modern bioenergy can be promoted both on a small-scale for local use in stand-alone applications or micro-grids, as well as on a large-scale for production and commoditization of bioenergy. At the same time, modern bioenergy can replace inefficient and less sustainable bioenergy systems[5].

The Government of Trinidad and Tobago (GORTT) supported by the ICAO – European Union project updated and submitted an improved State Action Plan to reduce CO_2 emissions from international aviation in 2015. The Action Plan for CO_2 Emissions Reduction for Trinidad and Tobago (APERTT) provides a comprehensive approach with a basket of measures for Trinidad and Tobago to reduce aviation CO_2 emissions, including the initiative to explore the feasibility to develop and use of sustainable alternative fuels.

The following feasibility study is a result of ICAO – European Union support for Trinidad and Tobago's determination to make progress towards the sustainable development of its aviation sector, and specifically assessing the use of sustainable aviation fuels (SAFs), including sustainable fuels for ground support equipment (GSE). The main objective of this study is to provide a comprehensive overview on the potential for production and use of socially acceptable, environmentally friendly, and economically viable drop-in SAFs and sustainable fuels for GSE in Trinidad and Tobago. The findings presented will be those that could offer the greatest benefit to society and the environment, and that concur with the direction the GORTT is taking to fulfil its responsibilities under the ICAO assembly and the Intended Nationally Determined Contributions (INDCs) determined by the Paris Agreement.

1.1 ICAO AND ENVIRONMENT

The International Civil Aviation Organization (ICAO) is a UN specialized agency, established by States in 1944 to manage the administration and governance of the Convention on International Civil Aviation (Chicago Convention).

ICAO works with the Convention's 191 Member States and industry groups to reach consensus on international civil aviation Standards and Recommended Practices (SARPs) and policies in support of a safe, efficient, secure, economically sustainable and environmentally responsible civil aviation sector. These SARPs and policies are used by ICAO Member States to ensure that their local civil aviation operations and regulations conform to global norms, which in turn permits more than 100,000 daily flights in aviation's global network to operate safely and reliably in every region of the world[6].

During the 37th ICAO Triennial Assembly Session in 2010, Member States agreed to the collective global aspirational goals for the international aviation sector of improving fuel efficiency by 2 per cent per year from 2020 and keeping net CO_2 emissions at the same levels (i.e. carbon neutral growth from 2020). In order to achieve such goals, ICAO Assembly adopted a "basket of measures" to reduce aviation CO_2 emissions consisting of the following seven categories[7] of mitigating measures:

1. Aircraft-related technology development;
2. Alternative fuels;
3. Improved air traffic management and infrastructure use;
4. More efficient operations;
5. Market-based measures;
6. Regulatory measures/other; and
7. Airport improvements.

ICAO launched a voluntary programme inviting States to develop a State Action Plan on CO_2 emissions reduction from international aviation incorporating the above mitigation measures through its implementation. This programme encourages States to report their CO_2 mitigation activities to ICAO and promotes improved

[4] Bioenergy refers to the energetic use out of a material of biological origin, such as biomass or biofuels.
[5] Nogueira, L. et al., 2015. Sustainable development and Innovation. In: Bioenergy & Sustainability: Bridging the Gaps. Paris: Cedex, pp. 184-217.
[6] ICAO: About ICAO. Retrieved from http://www.icao.int/about-icao/Pages/default.aspx
[7] ICAO DOC 9988 - Guidance on the Development of States' Action Plans on CO_2 Emissions Reduction Activities, paragraph 1.1.2. Order Number: 9988, ISBN 978-92-9249-223-6. March 17th, 2014.

communication on environmental matters within the aviation industry. SAFs were identified as an important mitigation measure to help States achieve ICAO's aspirational goals including Carbon Neutral Growth[8]. The specific focus of SAFs is on drop-in fuels as these fuels are fully compatible with fuel certification requirements, existing fuel transport, distribution and storing infrastructure, as well as current aircraft engines requiring no additional infrastructure for its use or handling. ICAO is actively engaged in activities to promote and facilitate the emergence of drop-in SAFs by exchanging and disseminating information, fostering dialogue among States and stakeholders, and carrying out dedicated work as requested by ICAO Member States to inform decision making[9].

ICAO Environment, within ICAO's Air Transport Bureau, provides guidance and support to Member States in their efforts to improve the environmental performance of aviation. ICAO developed a "range of Standards and Recommended Practices (SARPs), policies and guidance material for the application of integrated measures"[10] to achieve the following three main goals adopted by ICAO in 2004:

a. limit or reduce the number of people affected by significant aircraft noise;
b. limit or reduce the impact of aviation emissions on local air quality; and
c. limit or reduce the impact of aviation greenhouse gas emissions on the global climate.

The Committee on Aviation Environmental Protection (CAEP), a technical committee of the ICAO Council, is undertaking most of this work, assisting the ICAO Council in "formulating new policies and adopting new SARPs related to aircraft noise and emissions, and more generally to aviation environmental impact[11]. This technical committee is constituted of 24 Member States and 16 Observers from States and international organizations representing environmental interest of the aviation sector.

In addition to the work being carried out by CAEP, several tools and documents have been developed to assist participating States reach their emissions reductions goals, many of which are publically available at ICAO's website[12]. The following documents and tools are accessible specifically to support the Member States pursue State Action Plans[13]:

i. ICAO Doc 9988 - Guidance Document for the Development of States' Action Plans - Includes guidance on the baseline calculation, the basket of mitigation measures and the quantification of selected measures.
ii. Environmental Benefits Tool - Provides a framework to automatize the calculation of the baseline CO_2 emissions in international aviation, and the estimation of expected results obtained through the implementation of mitigation measures selected in ICAO's basket of measures.
iii. ICAO Carbon Emissions Calculator - Allows the States to estimate the CO_2 emissions attributed to air travel, using only a limited amount of input information.
iv. ICAO Fuel Savings Estimation Tool (IFSET) - Can be used to estimate fuel savings obtained through operational measures in a manner consistent with approved models.
v. ICAO Green Meetings Calculator - Can be used to support decision-making by selecting meeting locations with minimum CO_2 footprints from air travel.
vi. Action Plan on Emissions Reduction (APER) website - Interactive website geared towards States' action plan focal points to assist them in preparing and submitting their Action Plans to ICAO.
vii. Aviation Environmental Systems (AES) - An efficient CO_2 emissions monitoring system for international aviation developed in each selected Member State.

1.2 ICAO-EUROPEAN UNION ASSISTANCE PROJECT: CAPACITY BUILDING FOR CO_2 MITIGATION FROM INTERNATIONAL AVIATION

On 17 December, 2013, ICAO and the European Union signed an agreement to implement an assistance project: Capacity Building for CO_2 Mitigation from International Aviation, to assist fourteen selected States in reducing CO_2 emissions from the aviation sector. Trinidad and Tobago is one of the States selected for inclusion in this programme.

The ICAO-European Union agreement on Capacity Building for CO_2 Mitigation from International Aviation, a subcomponent of ICAO Environment, is a program to support 14 selected Member States in Africa and the Caribbean. It offers guidance, resources to prepare feasibility studies, and access to financial resources through partnerships with interested parties in support of the implementation of mitigation measures described in their Action Plans. The overarching objective is to contribute to the mitigation of CO_2 emissions from international aviation by implementing capacity building activities that will support the development of low carbon air transport and environmental sustainability[14]. This program focuses on the following three areas of activity:

a. Improve capacity of the national civil aviation authorities to develop their Action Plans on CO_2 emissions reduction from international aviation;

[8] For more information on ICAO's Aspirational Goals, refer to http://www.icao.int/annual-report-2013/Pages/progress-on-icaos-strategic-objectives-strategic-objective-c1-environmental-protection-global-aspirational-goals.aspx
[9] ICAO Environment: Alternative Fuels: Questions and Answers. Retrieved from http://www.icao.int/environmental-protection/Pages/AltFuel-IcaoAction.aspx
[10] ICAO Environment: Environmental Protection. Retrieved from http://www.icao.int/environmental-protection/Pages/default.aspx
[11] ICAO Environment: Committee on Aviation Environmental Protection (CAEP). Retrieved from http://www.icao.int/ENVIRONMENTAL-PROTECTION/Pages/CAEP.aspx
[12] ICAO Environment: Retrieved from http://www.icao.int/environmental-protection/Pages/default.aspx
[13] ICAO Environment: Retrieved from http://www.icao.int/environmental-protection/Pages/default.aspx
[14] ICAO Environment: ICAO - European Union Joint Assistance Project. Retrieved from http://www.icao.int/environmental-protection/Pages/ICAO_EU.aspx

b. Develop an efficient CO_2 emission monitoring system for international aviation in each selected Member State; and

c. Identify, evaluate, and partly implement priority mitigation measures, specifically those measures included within the States' Action Plans that can be replicated by other States.

The model can be replicated and adapted to additional countries creating a global system of cooperation to take actions to reduce CO_2 emissions.

This study looks at the potential of Trinidad and Tobago to produce and use SAFs and sustainable fuels for GSE. It evaluates national conditions (legislation, existing structures, related stakeholders, roles of government and industry, etc.), feedstocks, applicable production processes, human capital, available markets, environmental impacts, and pertinent legal and political frameworks. It also identifies obstacles and alternatives to overcome challenges, and offers a detailed roadmap on best practices adapted to the specific conditions of Trinidad and Tobago (economic, geographic, social, environmental, etc.) for the successful deployment of SAFs and sustainable fuels for GSE.

1.3 TRINIDAD AND TOBAGO NATIONAL CONDITIONS

Trinidad and Tobago, officially the Republic of Trinidad and Tobago, is a twin island country situated in the Caribbean, south of the West Indian archipelago close to the Venezuelan coast. It has an estimated population of 1,360,088[15]. It is the third richest country in the Americas by Gross Domestic Product (GDP) estimated at US$24,000 per capita or US$32,600 by purchasing power parity[16].

Trinidad and Tobago's wealth is mostly attributed to the exploitation of oil and natural gas, accounting for about 40 per cent of GDP and 80 per cent of exports[17]. The production of petrochemicals is divided as illustrated in Figure 2.

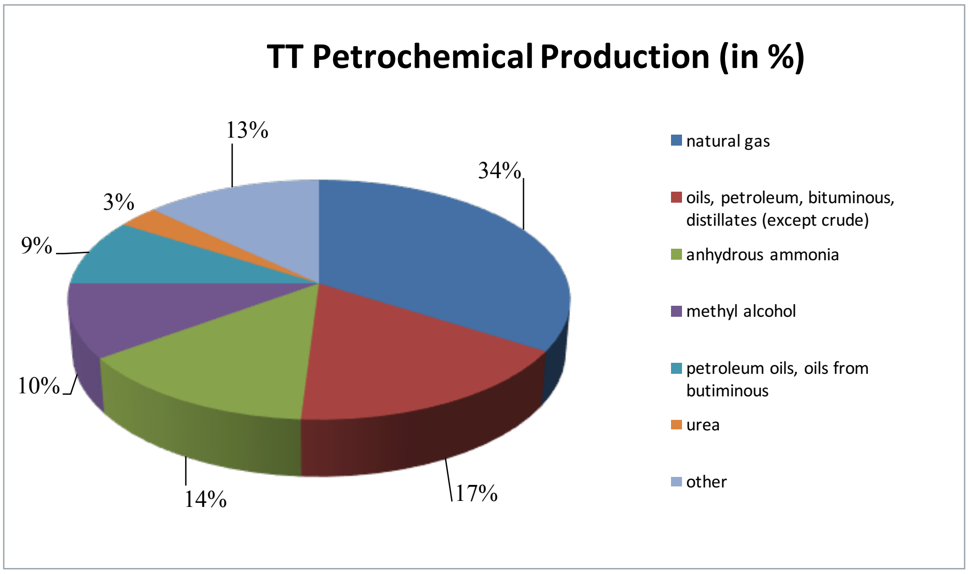


FIGURE 2
Trinidad and Tobago Petrochemical production[18]

[15] World Bank. Population total Trinidad and Tobago, 2015. Retrieved from http://data.worldbank.org/indicator/SP.POP.TOTL?locations=TT

[16] World Bank. GDP per capita, PPP (current international $), 2015. Retrieved from http://data.worldbank.org/indicator/NY.GDP.PCAP.PP.CD?locations=TT

[17] Central Bank of Trinidad and Tobago. Output Annual. Retrieved from http://www.central-bank.org.tt/content/output-annual-0

[18] MIT Media Lab and the Center for International Development at Harvard University. R. Haussmann, Cesar Hidalgo, et.al. Retrieved from http://atlas.media.mit.edu/en/profile/country/tto/

The energy industry operates under a robust scheme of subsidies which has created a substantial liability for the public sector. The Government of the Republic of Trinidad and Tobago (GORTT) decided to alleviate this burden and diversify their energy supply by launching action plans promoting the production and use of renewable sources of energy. These plans also help Trinidad and Tobago to achieve its commitment to reduce its impact on the climate, as well as comply with their Intended Nationally Determined Contributions (INDCs) under the 2015 Paris Agreement[19].

Fossil fuels remain the most productive and supported economic sector in Trinidad and Tobago. After Trinidad and Tobago declared its independence, aggressive support from the GORTT to develop the fossil fuel and petrochemical industries reduced activity from several other economic sectors, most significantly the agricultural sector[20]. Historically, sugar cane, cocoa, and coffee were the country's main agricultural products, mostly aimed for export to Europe. After independence, an increase in agricultural labour costs and volatile international commodities' markets resulted in sharp reductions in budgetary allocations to agriculture and animal husbandry[21]. Today, agricultural production in Trinidad and Tobago concentrates mainly on niche markets like coconut water and hot peppers, as well as on subsistence crops to help reduce food security risks. Rice, citrus, corn, cassava, peanuts, and pigeon peas are also being grown to further diversify agricultural output[22]. Despite efforts from the Ministry of Agriculture, Land and Fisheries to increase production beyond niche markets and expand the reach of agriculture to address the dietary needs of the population with local produce, currently agriculture only accounts for 8 per cent of food supply, contributing approximately 0.5 per cent of the country's GDP in 2009, and directly employing about 3.8 per cent of the population[23].

1.3.1 LEGISLATION AND EXISTING STRUCTURES FOR THE DEPLOYMENT OF SAFS

According to data provided by the Ministry of Planning and Development (MPD), the Trinidad and Tobago Civil Aviation Authority (TTCAA), and the Ministry of Energy and Energy Industries (MEEI), there is an existing policy and regulatory framework for renewable energy and energy efficiency in Trinidad and Tobago but there is no existing legislation specific to the production and use of SAFs for transport. Nevertheless, several government offices have been working actively on R&D activities to transform the Republic into a low carbon emitter through sustainable technologies such as wind and solar energy for power generation. In terms of fuels, the state is relying on the introduction of compressed natural gas (CNG) to lower emissions and the exploration of other alternatives for the future.

In the aviation sector, meaningful work has already taken place on aircraft fuel efficiency improvements, airport navigation systems, and aircraft and airport operations. The following initiatives have been launched, creating a structure of programmes to support the healthy and long term development of a low carbon aviation sector:

i. Fuel Savings and Emissions Reduction Plan for the PIARCO Flight Information Region
ii. National Climate Change Policy and draft on Carbon Reductions Strategy
iii. Action Plan on Emissions Reduction for Trinidad & Tobago and the PIARCO Flight Information Region - APERTT
iv. Carbon Low Emission Program -CLEP
v. Aviation Environmental Working Group- AEWG
vi. Fuel Management Committee

The AEWG is headed by the TTCAA and embraces several government entities working in collaboration to implement environmental initiatives in Trinidad and Tobago. Participants involved in the AEWG are illustrated in Figure 3:

FIGURE 3
AEWG representatives[24]

[19] At COP 21 in Paris, Parties to the UNFCCC reached a historic agreement to combat climate change and to accelerate and intensify the actions and investments needed for a sustainable low carbon future. The Paris Agreement requires all Parties to put forward their best efforts through "nationally determined contributions" (NDCs) and to strengthen these efforts in the years ahead (http://unfccc.int/paris_agreement/items/9485.php).
[20] New Agriculturist. Country profile - Trinidad and Tobago. Retrieved from http://www.new-ag.info/en/country/profile.php?a=3023
[21] New Agriculturist. Country profile - Trinidad and Tobago. Retrieved from http://www.new-ag.info/en/country/profile.php?a=3023
[22] Ministry of Agriculture, Land and Fisheries, personal communication, October 12, 2016.
[23] Caribbean Agricultural Research & Development Institute (CARDI) (2016). Country Profile. Retrieved from http://www.cardi.org/country-offices/trinidad-tobago/

The AEWG is divided into six Specific Working Groups for Trinidad and Tobago (SWGTT). "The specific working groups were created to strengthen the participation and involvement of other stakeholders to explore areas of reducing CO_2 emissions"[24]. The SWGTT are organized as illustrated on Figure 4:

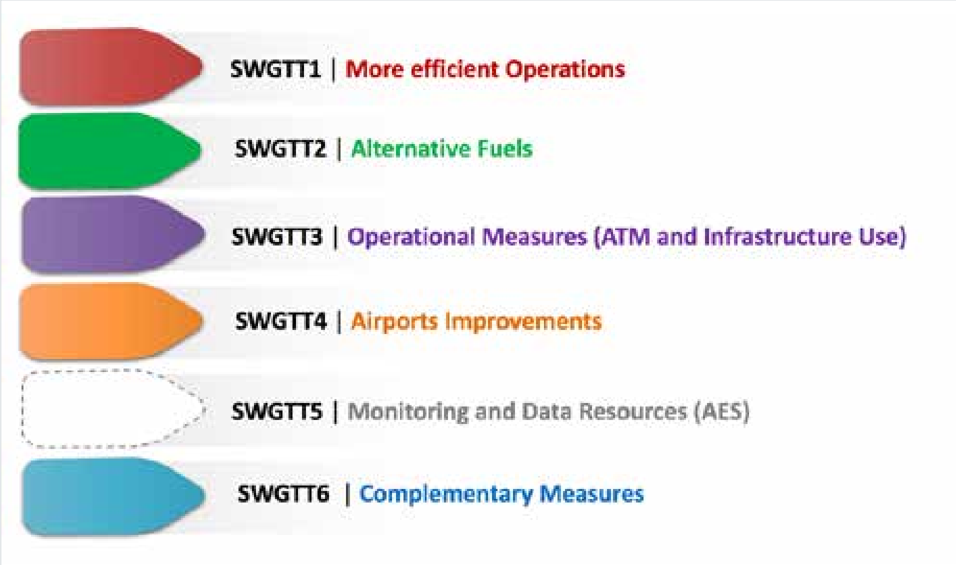


FIGURE 4
Specific Working Groups for Trinidad and Tobago - Grouping and denomination[25]

The MPD leads the Specific Working Group on Alternative Fuels or SWGTT2. Other members of the AEWG include the TTCAA, the National Petroleum Marketing Company Limited (NP), the Ministry of Energy and Energy Affairs, the Ministry of Trade and Industry, and the Petroleum Company of Trinidad and Tobago Limited (Petrotrin).

The SWGTT2 main focus is on the following six actions[26]:

1. Analyzing the experiences and successful cases of other countries.
2. Creating partnerships with other countries and key stakeholders in addition to those already represented within the Specific Working Groups.
3. Identifying and obtaining financial and technical assistance to perform the initial feasibility studies.
4. Estimating the provision of suitable fiscal incentives needed, which are consistent with the National Carbon Reduction Strategy and the National Climate Change Policy.
5. Promoting special incentives for airlines flying to Trinidad and Tobago on alternative fuels.
6. Facilitating cooperative actions with other countries to support Caribbean Airlines Limited and the other commercial air carriers to begin flights with a percentage of drop-in alternative fuels from other countries where these types of fuels are available.

The AEWG gives a strong structure to embark on the research and development for the production and use of SAFs and sustainable fuels for GSE in Trinidad and Tobago. Its work, dedication and cooperation with international partners like ICAO ensure that actions are taken towards the deployment of sustainable fuels for the aviation industry.

[24] Trinidad and Tobago- Action Plan on Emissions Reductions for Trinidad and Tobago (APPERTT) and the Piarco FIR. Retrieved from https://www.icao.int/environmental-protection/Lists/ActionPlan/Attachments/15/Action-Plan-on-Emissions-Reduction-for-Trinidad-and-Tobago-(APERTT).pdf

[25] Source: Trinidad and Tobago- Action Plan on Emissions Reductions for Trinidad and Tobago (APPERTT) and the Piarco FIR.

[26] Trinidad and Tobago Civil Aviation Authority (TTCAA) (2016, June 29). Trinidad and Tobago- Action Plan on Emissions Reductions for Trinidad and Tobago (APPERTT) and the Piarco FIR. Retrieved from http://www.icao.int/environmental-protection/Lists/ActionPlan/Attachments/15/Action-Plan-on-Emissions-Reduction-for-Trinidad-and-Tobago-(APERTT).pdf

1.3.2 THE ROLE OF GOVERNMENT AND INDUSTRY

The role of the GORTT is crucial for the competitive development of a sustainable aviation sector. Local and international success of this new industry depends partly on the development of targeted policy and subsidy schemes to promote investment and allow for a competitive market for SAFs.

In addition, collaboration between the GORTT and private and public industry is needed to share risks and associated costs common to the growth of nascent industries. Such collaboration is based on capital resources (investment, financing, etc.), as well as on technology exchange, R&D, capacity building, communication campaigns, and education at all levels of society. The understanding and consequent endorsement from the public for the adoption of SAFs and sustainable fuels for GSE is crucial for long term success. This can be attained by an open and transparent cooperation between public, private, and academic sectors coupled with extensive awareness and informational campaigns for the general public.

1.3.3 CURRENT ENERGY FRAMEWORK ON ALTERNATIVE FUELS IN TRINIDAD AND TOBAGO

Trinidad and Tobago has been exploring the use of sustainable fuels for transport not only to diversify fuel supply but to help decrease the burden to the GORTT resulting from subsidies placed on conventional fossil fuels. It is important to note that not all alternative fuels are necessarily sustainable fuels. CNG is an alternative fuel obtained from a source other than petroleum being pursued by the GORTT. Though CNG reduces CO_2 emissions when compared with conventional gasoline and diesel fuels, it is still derived from fossil fuels and thus does not qualify as sustainable or renewable. Electricity and gas-to-liquid fuels are also not considered sustainable unless the feedstock used for conversion is derived from renewable and sustainable resources.

a) Compressed Natural Gas

Trinidad and Tobago controls "large natural gas reserves and gas extraction has increased significantly over the years from 177 billion cubic feet (bcf) in 1990 to 811 bcf in 2011."[27] The National Gas Company of Trinidad and Tobago Limited (NGC) "has provided in excess of TT$6 billion in taxes to the treasury, and, since 1992, over TT$4 billion in dividend payments to the Government of Trinidad and Tobago. NGC's value maximization has therefore been contributing to the overall macroeconomic development of the country, as well as sharing the benefits of natural gas to the citizens of Trinidad and Tobago."[28]

Currently, the GORTT is aggressively promoting the use of compressed natural gas (CNG) as an alternative fuel for land transport through the NGC CNG mandate. "The NGC CNG mandate was designed to accelerate and expand the use of [...] CNG as a major, alternative, transportation fuel in the country."[29] On October 7th, 2016, the Minister of Finance Mr. Colm Imbert, conducted a public reading of the annual national budget for 2017 endorsing the use of CNG and offering the following fiscal incentives to encourage the population to switch to this new cleaner and cheaper fuel:

- Removal of Motor Vehicle Tax and Value Added Tax on imported vehicles (less than 2 years old) which are manufactured to use natural gas.
- For Individuals – 25 per cent tax credit on the cost of converting a vehicle to use CNG up to a conversion cost limit of TT$10,000.00 per vehicle.
- For Fleets – Capital uplift of 130 per cent for wear and tear allowance on the cost of converting a vehicle to use CNG.
- For Installers – Capital uplift of 130 per cent for wear and tear allowance on the cost of plant, machinery and equipment needed to provide CNG installations.
- For Maxi-Taxi owners (shuttle buses) – Grant of TT$45,000 to TT$75,000 for small and large deregistered, destroyed old diesel powered maxi-taxi[30].

[27] Natacha C. Marzolf, Fernando Casaquo Cañeque, Johanna Klein, Detlef Loy. A Unique Approach for Sustainable Energy in Trinidad and Tobago. Inter-American Development Bank. Retrieved from http://www.energy.gov.tt/wp-content/uploads/2016/08/A-Unique-Approach-for-Sustainable-Energy-in-Trinidad-and-Tobago.pdf

[28] The National Gas Company of Trinidad and Tobago Limited. Present Day NGC
NGC: History and National Economic Development. Retrieved from http://ngc.co.tt/about/history/present-day/

[29] The National Gas Company of Trinidad and Tobago (2016). Introducing NGC CNG, "CNG is our business." Retrieved from http://ngc.co.tt/cng/

[30] The National Gas Company of Trinidad and Tobago (2016). Introducing NGC CNG, CNG is our business. Retrieved from http://ngc.co.tt/cng/

For the GORTT, the use of CNG means a reduction in noise pollution as engines run smoother on this cleaner fuel, a decrease in overall air emissions resulting in lower health costs form airborne disease cases, a reduction of the Government's subsidy liability burden resulting from the use of gasoline or diesel, the generation of foreign income from the sale of the displaced liquid fuels to foreign markets at international fuel prices, and a reduction in overall GHG emissions. According to research conducted by the California Air Resources Board (CARB) a natural gas vehicle (NGV) emits "13 to 21 per cent fewer GHG emissions than a comparable gasoline or diesel fuelled vehicle on a well-to-wheel basis" . Table 1 below illustrates CARB's findings, data based on the Argonne National Laboratory's complete full fuel cycle analysis using the latest U.S. EPA figures[31].

TABLE 1
Emissions Reductions (%) of NGV Compared to In-Use Gasoline and Diesel Vehicles.
Source: NVGAmerica[31]

Pollutant	Light-Duty Car		Light-Duty Truck		Heavy Duty Truck	
	CNG vs. Gasoline				CNG vs. Diesel	
	2002	2007	2002	2007	2002	2007
GHG	18	18	25	25	25	25
NO_x	91	34	97	91	95	88
PM_{10}	50	0	98	12	98	22

As fuel efficiency improves on newer models and the percentage of overall noxious emissions decreases, CNG shows a consistent reduction on GHG emissions through the years.

From those findings, Table 2 shows reductions offered by CNG vs gasoline and diesel fuel specific to CO_2 emissions:

TABLE 2
CO_2 Emissions Reduction for CNG. Source: NVGAmerica[31]

Light-Duty Vehicles	Carbon Intensity of Fuel (gCO_{2e}/MJ)	CO_2 Reductions Relative to Gasoline (%)
Gasoline	96	NA
CNG	68	29
Heavy-Duty Vehicles	**Carbon Intensity of Fuel (gCO_{2e}/MJ)**	**CO_2 Reductions Relative to Diesel (%)**
Diesel Fuel	95	NA
CNG	68	20

b) Hybrid Vehicles

The GORTT is promoting the use of plug-in hybrid electric vehicles (PHEV), a "vehicle that is capable of being propelled by a combination of an internal combustion engine and an on-board rechargeable energy system"[32], by eliminating the motor vehicle tax on the following:

- a new hybrid vehicle, with an engine size not exceeding 1799 cc; or
- a used hybrid vehicle, with an engine size not exceeding 1799 cc, and which is not older than four years from the year of manufacture, which is imported for private or commercial use on or after 1st January, 2015 and before 1st January, 2020.

[31] NGV America. Environmental Benefits: Green House Gas Emissions. Retrieved from http://www.ngvamerica.org/natural-gas/environmental-benefits/
[32] Fifth Session Tenth Parliament of TT. Act No 2 of 2015, Chap. 48:50 amended, PART XVI MOTOR VEHICLES AND ROAD TRAFFIC, 17: j- 8B. Retrieved from http://www.ttparliament.org/legislations/a2015-02.pdf

The environmental benefits offered by PHEVs are highly dependent on several factors like the type of vehicle, battery capacity, how the vehicle is driven, charging frequency, fuel efficiency under electric charge and fossil fuel burn, and the carbon intensity of the electrical grid, among others. Though a fair comparison with other vehicles is therefore highly complex, direct emissions emitted through the tailpipe of PHEVs are "typically lower than those of comparable conventional vehicles"[33]. Social benefits resulting from the use of PHEVs as compared to NGVs are somehow diminished as in Trinidad and Tobago PHEVs still use a portion of gasoline and diesel liquefied fuels to operate, minimizing to a lesser extent the liability burden on the National Budget from liquid fuel subsidies than the use of CNG vehicles. Additionally, the electrical grid in Trinidad and Tobago is powered by natural gas; potential environmental and social benefits from PHEVs would be best optimized with electricity generated from renewable resources such as wind, solar, of biomass.

CO_2 emissions reductions from hybrid vehicles can vary significantly depending on the carbon intensity of the electrical grid and the type of vehicle. Carbon intensity from an electrical grid can vary from low, to medium, and high depending on the feedstock used to generate the electricity. Figure 5 illustrates three different scenarios for a low and high carbon intensity electrical grid.

FIGURE 5
Grid profiles representing varying levels of carbon intensity[34]

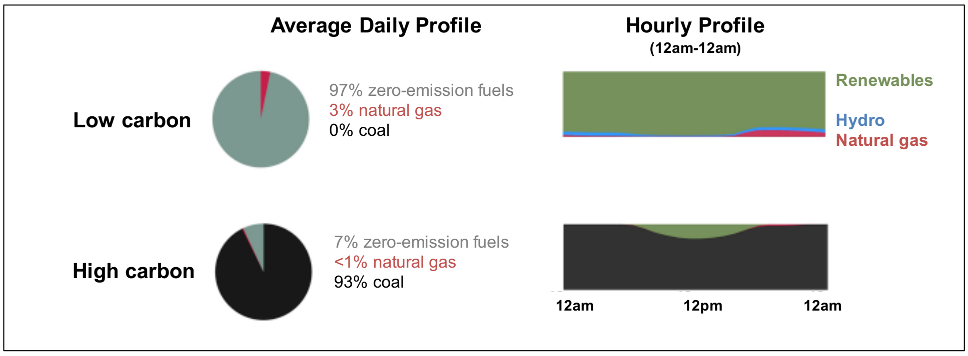
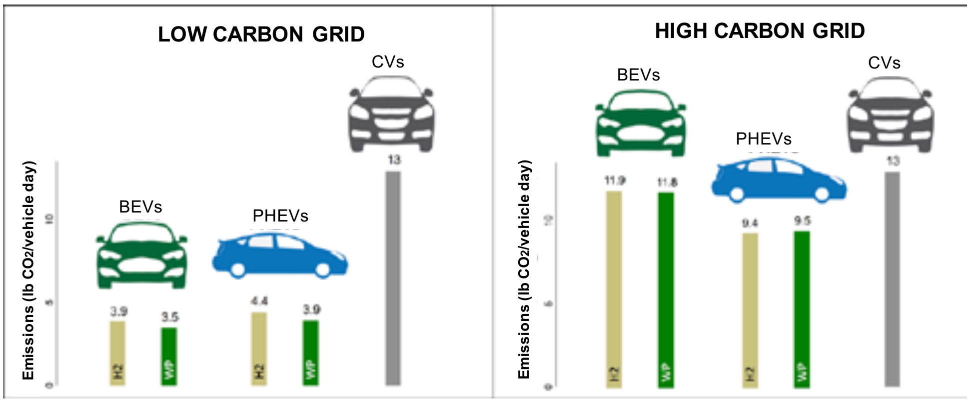


Figure 6 compares total CO_2 emissions for a battery electric vehicle with a 200 mile (320 km) all electric range[35] (BEV200), a plug-in hybrid electric vehicle (PHEV), and a conventional vehicle (CV) for both grid profiles[36]. In the case of BEV200 and PHEVs, the first bar refers to vehicles charged only at home and the second bar refers to vehicles that can be charged at home or at the workplace[37].

FIGURE 6
Comparison of total BEV200 and PHEV CO_2 emissions with emissions from a CV on a low and high carbon grid[34].



[33] U.S. EPA. Energy Efficiency and Renewable Energy: Alternative Fuels Data Center. Emissions from Hybrid and Plug-In Electric Vehicles. Retrieved from https://www.afdc.energy.gov/vehicles/electric_emissions.php

[34] J. McLaren, J. Miller, E. O'Shaughnessy, Eric Wood, E. Shapiro. Emissions Associated with Electric Vehicle Charging: Impact of Electricity Generation Mix, Charging Infrastructure Availability, and Vehicle Type. National Renewable Energy Laboratory Prepared under Task No. VTP2.0100. National Renewable Energy Laboratory (NREL). Retrieved from https://www.afdc.energy.gov/uploads/publication/ev_emissions_impact.pdf

[35] Apurba Sakti, Jeremy J. Michalek, Erica R.H. Fuchs, Jay F. Whitacre. A techno-economic analysis and optimization of Li-ion batteries for light-duty passenger vehicle electrification. Journal of Power Sources 273 (2015) 966e980, ELSEVIER. Retrieved from http://www.cmu.edu/me/ddl/publications/2014-JPS-Sakti-etal-Techno-Economic-EV-Battery.pdf

[36] All vehicles require the installation of specialized charging equipment to supply 240 volts of alternating current, and a dedicated 40 amp circuit.

[37] Joyce McLaren, John Miller, Eric O'Shaughnessy, Eric Wood, and Evan Shapiro. Emissions Associated with Electric Vehicle Charging: Impact of Electricity Generation Mix, Charging Infrastructure Availability, and Vehicle Type. NREL/TP-6A20-64852, April 2016. Retrieved from https://www.afdc.energy.gov/uploads/publication/ev_emissions_impact.pdf

As illustrated on Figure 5, significant CO_2 reductions from BEVs and PHEVs as compared to CVs are best achieved under a low carbon intensity grid scenario, and emissions are only slightly decreased if fed by a high carbon intensity electrical grid.

c) Gas-to-Liquid Fuels

Though not renewable, natural gas is a cleaner burning fuel that can be converted into other alternative fuel for transport vehicles in addition to CNG. For example, the processing of natural gas to Gas-to-Liquid (GTL) fuels utilizing Fischer Tropsch (FT) technology produces cleaner burning diesel, naphtha, and jet fuel among potential products. The resulting GTL fuel offers life-cycle GHG emissions benefits over conventional fuels that vary depending on processing technologies, vehicle type, drive cycle, and engine calibration. Figure 7 shows results from a joint research effort of Sasol, Sasol-Chevron, and Daimler Chrysler into the benefits in emissions reductions of GTL Diesel for land vehicles without any hardware adaptation.

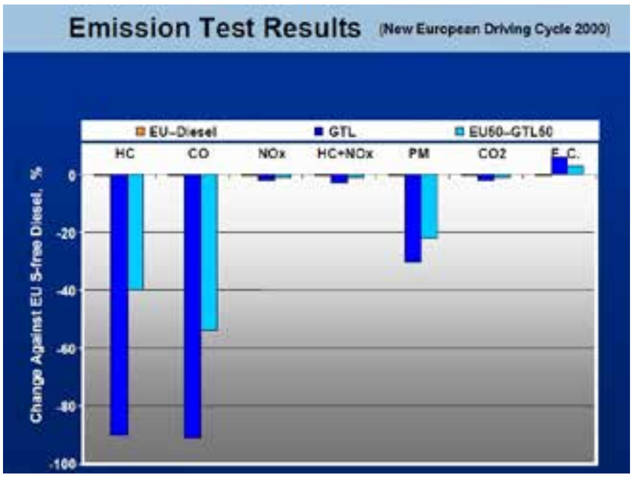


FIGURE 7

GTL emissions test results: Mercedes-Benz E 220 CDI Limousine[38]

Though CO_2 emissions reductions are negligible, tests run with an intercooled and turbocharged marine Euro III diesel engine revealed that emissions of particulates, NOx and carbon monoxide (CO) were reduced by 33.5 per cent, 5.2 per cent and 19.5 per cent, respectively, with GTL compared to conventional diesel marine fuel[39], contributing to improved local air quality. Unfortunately, similar data on GHG emissions reductions is not available for GTL jet fuel yet.

Private institutions are currently planning to introduce two GTL plants utilizing FT technology in Trinidad and Tobago. NiQuan Energy (NETL) and a consortium of investors[40] have announced construction plans for GTL facilities for the production of cleaner burning diesel, naphtha, and kerosene/jet fuel.

A GTL plant is being planned for construction in E-IDCOT Cove Eco-Industrial and Business Park, in Tobago, starting in 2017-2018[42]. The business plan includes three stages of development starting with a small pilot plant of 500 bpd capacity for the production of GTL diesel and naphtha for a total investment of US$65 million. The second and third stages include 6800 bpd (US$ 395 million) and a 27,000 bpd (US$ 2.1 billion) GTL plants for the production of diesel, naphtha, and jet fuel. Further negotiations need to take place before any definitive steps are taken.

NETL purchased the assets of a GTL project located in Pointe-A-Pierre that went into receivership. The plant is set up for the production of 2400 bpd of GTL diesel (80 per cent) and naphtha (20 per cent). They will market their diesel output directly to Petrotrin for use in the marine sector. The investment is in the range of US$ 35,000 million and will come into production sometime in 2018.

The use of GTL jet fuel is not a new concept. Qatar Airways has been using this fuel since 2007 without any technical problems, and today their aircraft run on a fuel blend with 15 per cent GTL jet fuel. It is important to note, however, that natural gas is being used as feedstock for conversion and the resulting GTL jet fuel is not considered sustainable or renewable[41]. In order to improve the sustainability credentials of GTL jet fuel, Qatar Airways and Qatar Science and Technology Park are currently collaborating on a US$12.5 million project to further research on finding alternative sources of feedstock for the production of biomass to liquid (BTL) fuels. Following Qatar's example, NETL is also looking beyond GTL fuels to advanced FT fuels processed from sustainable sources of methane (CH4) in Trinidad and Tobago. Experience gained in the GTL process serves as a starting point for the efficient conversion of renewable CH4 into BTL-SAFs[42].

[38] Rudolf R. Maly. Effect of GTL Diesel Fuels on Emissions and Engine Performance. Research and Technology, Stuttgart, Daimler Chrysler. Retrieved from http://infohouse.p2ric.org/ref/46/45872.pdf

[39] S. Bengtsson K. Andersson E. Fridell. "Life cycle assessment of marine fuels: A comparative study of four fossil fuels for marine propulsion." Department of Shipping and Marine Technology Division of Sustainable Ship Propulsion Chalmers University Of Technology, ISSN 1652-9189 Report No. 11:125, Gothenburg, Sweden, 2011. Retrieved from http://www.dma.dk/themes/LNGinfrastructureproject/Documents/Fuels%20and%20environment/LCA%20of%20four%20possible%20marine%20fuels.pdf

[40] Intellectual Capital Llc., personal communication, October 11, 2016.

[41] Qatar Airways Group, personal communication, December 1, 2016.

[42] Green Air Online. Qatar Airways first to benefit from commercial introduction of synthetic GTL jet fuel at Doha. Retrieved from http://www.greenaironline.com/news.php?viewStory=1639

2. METHODOLOGY

2.1 LITERATURE REVIEW AND SECONDARY DATA

A literature review was conducted to assess national conditions in Trinidad and Tobago as well as global development for the production and use of SAFs and sustainable fuels for GSE.

Significant advances have been achieved by different ministries in Trinidad and Tobago to address climate change concerns and GHG reductions from the transport sector. However, no specific work has been conducted that evaluates the GHG reduction potential and deployment viability of SAFs and sustainable fuels for GSE in Trinidad and Tobago. Nonetheless, the GORTT's decision to participate in the ICAO-European Union Assistance Project: Capacity Building for CO_2 Mitigation from International Aviation sends a clear message about the country's commitment to sustainable growth for the aviation sector.

Research material evaluating regional and local potential for deployment of SAFs is limited in Trinidad and Tobago, similar to other regions of the world considering that this is a nascent industry. In this regard, secondary data was also collected on processing technology developments, feedstock generation, advanced conversion processes, and the entire supply chain including the willingness of distributors and end users to adopt the use of SAFs and sustainable fuels for GSE.

2.2 INTERVIEWS AND ELECTRONIC DATA COLLECTION

Data collected during in-person and telephone interviews, as well as via email, helped reach more accurate and comprehensive conclusions for this study. In person meetings were conducted for three weeks during the months of September and October, 2016. Table 3 shows the complete list of stakeholders who participated in in-person interviews and provided valuable data for this study:

TABLE 3
In Person Interview Participants ;

No.	Agency	Participant/s
1	Airports Authority of Trinidad and Tobago (AATT)	Sherwyn Seyjagat; Renee Deane
2	Caribbean Airlines Limited (CAL)	Brent Gaspard
3	Environmental Management Authority (EMA)	Ryan Assui
4	GTL Expert	Harrold Cuffy
5	Intellectual Capital LTD	Brett McIntosh; Francis Bertrand
6	Ministry of Agriculture, Land and Fisheries (MALF)	Dale Nandlal, Albada Beekham, Farrah Aligour
7	Ministry of Energy and Energy Industries (MEEI)	Steffan Ramlogan; Hannibal Anyika
8	Ministry of Finance	Narine Charran; Kyren Greigg; Michael Raymond
9	Ministry of Planning and Development (MPD)	Kishan Kumarsingh; Sindy Singh
10	Ministry of Trade and Industry	Niki Brathwaite; Analise Ali
11	Ministry of Works and Transport	Roger Anthony; Sally Herralal
12	National Energy Corporation (NEC)	Arden Rodriguez
13	National Gas Company (NGC)	Curtis Mohammed; Roger Sant
14	National Petroleum (NP)	Sieudath Persad
15	OLADE Rep (MEEI)	Timmy Baksh
16	PETROTRIN	Shelvyn Dowlath; Curtis Paltoo; Varun Gangaram
17	Piarco Air Services (PAS)	Ashram Baitlal; Roger Lashley
18	AATT - ANR Robinson International Airport	Lindy Ann Redman; Julian Chance
19	Swissport	Davanand Raghoobar
20	SWMCOL	Maria Allong; Ronald Roach
21	E-IDECOT	Bernard Mitchell
22	Trinidad and Tobago Civil Aviation Authority	Ramesh Lutchmedial; Hema Dass; Henry Ricardo
23	University of the West Indies (UWI) St. Augustine	Denise Beckles; Grahamm King; Renique Murray
24	University of Trinidad and Tobago (UTT)	Ejae John

In-person interviews were semi-structured, where stakeholders were asked to share their experiences and perceptions on SAFs. According to their responses, the conversation went into greater detail on specific actions taken by their employers to reduce GHG emissions, any direct experiences with SAFs, their understanding and position on the GORTT's efforts to sustainable growth in the aviation sector, and any additional challenges foreseen with the adoption of SAFs. At the conclusion of the interview, operators were asked to provide any additional pertinent information via email.

Several airline representatives were contacted via email or a telephone/skype conversation. Though the sample is too limited to give statistically significant results, their feedback gave important information on market size and specific requisites on price, quality, and delivery of SAFs in Trinidad and Tobago. Additional data was obtained from interviews with technology providers and professionals who play an active role promoting sustainable growth in the aviation sector.

2.3 ANALYTICAL FRAMEWORK: QUALITATIVE AND QUALITATIVE DATA ANALYSIS

As previously stated, the objective of this study is to evaluate the potential for production and use of socially acceptable, environmentally friendly, and economically viable drop-in SAFs and sustainable fuels for GSE in Trinidad and Tobago. While gaining access to data specific to Trinidad and Tobago was challenging at times, economic data that would allow a quantitative analysis were easier to obtain. Conversely, data obtained on social and environmental matters was only suitable for conducting a qualitative analysis. A well-suited analytical framework to evaluate qualitative data is sequential data management and interpretation[43].

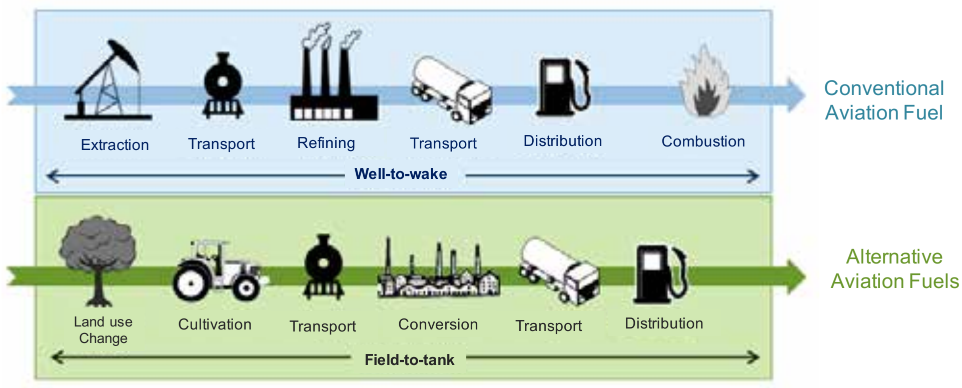
A cost-benefit analysis was not included in the economic evaluation for deployment of SAFs in Trinidad and Tobago as findings revealed that any such investment would be best realized under different national and international conditions.

[43] Ritchie, Lewis, McNaughton Nicholls, & Ormston, 2013.

3. SUSTAINABILITY CONCEPTS

The multiple steps and unit operations involved from feedstock production to final combustion of fuel constitute the full fuel life-cycle. To assess the emissions savings from the use of alternative fuels, a comprehensive accounting must be done of all emissions across all steps of the fuel's life-cycle, called a life-cycle analysis. If the total emissions from an alternative fuel are less than the total emissions from fossil fuel, there is an environmental benefit attributable to that fuel[44]. Figure 8 illustrates life-cycle emissions from fossil fuels as they compare to emissions from biofuels.

FIGURE 8
Fuel life-cycle emissions for fossil and biofuel[45].



Unlike in the conventional aviation fuel life-cycle, in the sustainable aviation fuel life-cycle CO_2 taken up by the biological matter comes out of the atmosphere, it is temporarily sequestered in the liquid fuel, and then is re-released back to the atmosphere when the fuel is combusted. Therefore, no additional carbon would be released into the atmosphere, as would be the case with conventional aviation fuels.

For the aviation industry, assessing fuel life-cycle GHG emissions is a particular topic for which increased harmonization amongst aviation stakeholders is important. Therefore, the Alternative Fuels Task Force (AFTF) was created within the ICAO Council technical Committee on environment, CAEP, and one of the tasks assigned was to develop a methodology to assess life-cycle emissions of sustainable aviation fuels[46].

When assessing the potential GHG savings of a fuel pathway, one key element to assess is land use change (LUC). Land use changes can lead to CO_2 emissions or sequestration due to carbon stock[47] changes in biomass, decomposing organic matter, and soil organic matter, which may translate into major impacts on the environmental profile of bioenergy. When dealing with LUC impacts, the distinction between direct (dLUC) and indirect LUC (iLUC) is frequently used, especially for certification purposes. ISO/TS 14067:2013, for instance, defines dLUC as a "change in the use or management of land within the product system being assessed", while iLUC is "a change in the use or management of land which is a consequence of direct land use change, but which occurs outside the product system being assessed"[48]. Unlike dLUC, iLUC cannot be directly measured or observed; instead, it is projected with economic models which are only able to capture both effects together.

Feedstocks that do not require land for their production (such as municipal or industrial waste), and those that do not require the substitution of crops or LUC, are estimated to have a low risk of inducing iLUC. Some LCA standards such as RSB-STD-04-001[49] have the ability to certify that a feedstock's production has a low iLUC risk. The AFTF is also undertaking work to define a methodology for the calculation of LUC.

[44] ICAO Environment: GFAAF - Aviation Alternative Fuel Live Feed. Retrieved from https://www.icao.int/environmental-protection/GFAAF/Pages/default.aspx
[45] Adapted from ICAO Environment: Fuel Life Cycle and GHG emissions. Retrieved from https://www.icao.int/environmental-protection/Pages/AltFuels_LifeCycle-Box.aspx
[46] Environment: Committee on Aviation Environmental Protection (CAEP). Retrieved from http://www.icao.int/ENVIRONMENTAL-PROTECTION/Pages/CAEP.aspx
[47] Carbon stock is the amount of carbon that is stored in a certain piece of land, i.e., carbon contained in the soil due to the decomposition of biomass (such as leaves) keeps carbon stored. This carbon stock can be reduced when the land is managed to cultivate; however, some crop management can help to increase the carbon stock by helping to integrate biomass.
[48] ISO/TS 14067: Preview Greenhouse gases -- Carbon footprint of products -- Requirements and guidelines for quantification and communication, 2013. Retrieved from https://www.iso.org/standard/59521.html
[49] Round Table on Sustainable Biomaterials. RSB Low iLUC Risk Biomass Criteria and Compliance Indicators: RSB reference code: [RSB-STD-04-001 (Version 0.3)]. Retrieved from https://rsb.org/wp-content/uploads/2017/02/RSB-STD-04-001-ver0.3RSBLowiLUCCriteriaIndicators.pdf

3.1 TECHNOLOGIES FOR SUSTAINABLE AVIATION FUEL PRODUCTION

The commercial aviation industry adopts rigorous safety standards and procedures in its equipment, operation, and maintenance, with indicators closely monitored. Thus, also taking into consideration that aircraft can be fuelled in different States, international specifications have been adopted for jet fuels. Two of the more widely utilized standards to define the kerosene-type fuel for aircraft are the American Society for Testing Materials (ASTM)[50] standard number D1655[51] and DEF STAN 91-91[52], setting requirements for composition, volatility, fluidity, combustion, corrosion, thermal stability, contaminants, and additives, among others. Moreover, the specifications produced by the Joint Inspection Group (JIG) Check List are relevant for supply into Jointly Operated Fuelling Systems[53]. The JIG Aviation Fuel Quality Requirements for Jointly Operated Systems combines the most stringent requirements of DEF STAN 91-91 and ASTM D1655.[54]

The 'drop-in' condition is a major requirement for the aviation industry. Any aviation alternative fuel that doesn't meet this condition[55] would present safety issues associated with risks of mishandling, and would require a parallel infrastructure to be implemented in all connected airports, creating unnecessary risks and costs.[56]

The ASTM D7566 standard regulates which technologies, under which circumstances and characteristics, can be used for producing fuels that are considered compliant with ASTM D1655 (standard regulating Jet A1 – AVTUR fuels) and therefore with DEF STAN 91-91, indirectly. DEF STAN 91-91 includes a clause in its Annex D which indicates that the use of alternative fuels is accepted as Jet A1, provided that it complies with the ASTM D7566 standard.

Table 4 shows five technologies or pathways that can currently produce drop-in SAFs. These technologies are Fischer-Tropsch, Fischer-Tropsch containing aromatics, Hydroprocessed Esters and Fatty Acids (HEFA) (these three can be blended up to 50 per cent in volume), Direct Sugars to Hydrocarbons producing Synthetic Iso-Paraffins (SIP) (blended up to 10 per cent), and Alcohol-to-Jet (ATJ) (blended up to 30 per cent). Many additional technologies are under evaluation by ASTM.

Technology	Maximum blend (%v/v)	Feedstocks
FT & FT-SKA	50	Wastes (MSW, etc.), coal, gas, sawdust
HEFA	5	Vegetable oils: palm, camelina, jatropha, used cooking oil.
Synthetic Iso-Paraffin	10	Sugarcane, sugar beet
ATJ (from isobutanol)	30	Sugarcane, sugar beet, sawdust, lignocellulosic residues (straw)

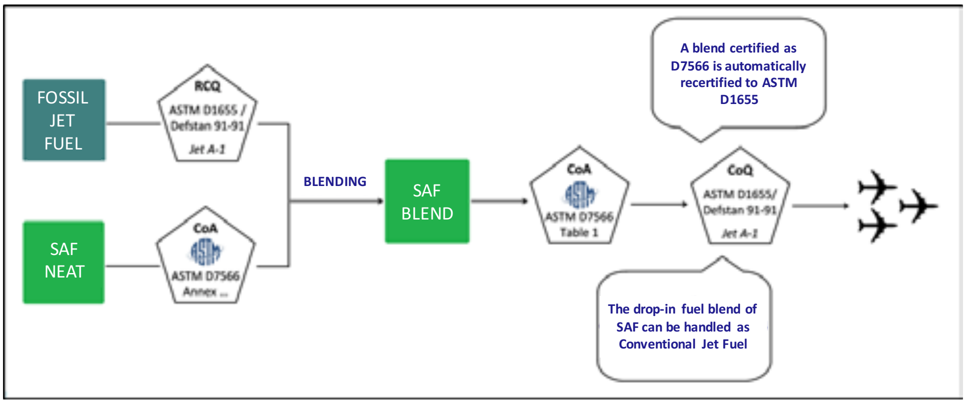
TABLE 4
Current technologies, maximum blend allowed and most common feedstocks for drop-in SAFs as defined under standard ASTM D7566. Source: Adapted from ICAO CAAF/2-WP/7.

[50] ASTM is one of the largest voluntary standards developing organizations in the world that provides a forum for the development and publication of international voluntary consensus standards for materials, products, systems and service. Retrieved from (https://www.astm.org/ABOUT/faqs.html#what)
[51] ASTM. ASTM D1655: Standard Specification for Aviation Turbine Fuels. Retrieved from https://www.astm.org/Standards/D1655.htm
[52] United Kingdom Ministry of Defence. Defence Standard 91-91: Turbine Fuel, Kerosine Type, Jet A-1. Retrieved from http://mindex-ltd.co.uk/wp-content/uploads/2015/02/91-91-issue-7-AMD-3-2.pdf
[53] Jointly Operated Systems are joint venture locations where jet fuel is supplied.
[54] Chuck, C., 2016. Biofuels for Aviation: Feedstocks, Technology, and Implementation. s.l.: Academic Press.
[55] Biodiesel/FAME or bioethanol are common examples of 'non drop-in' fuels.
[56] ICAO Environment: GFAAF - Aviation Alternative Fuel Live Feed. Retrieved from https://www.icao.int/environmental-protection/GFAAF/Pages/default.aspx

ASTM D7566 defines the requirements for the neat product (i.e., SAF) and the blend. Once the blend has been certified against ASTM D7566, it is a drop-in, and can be considered conventional Jet A1 as per the standards ASTM D1655 and DEF STAN 91-91. Figure 9 illustrates the blending and use process for synthetic SAFs and the different quality standards SAFs meets at different steps[57].

FIGURE 9

Blending and use process for SAFs synthetic fuels and quality standards[60]



The blend ratio refers to the final product (that is considered 'drop-in') to be introduced to the market. The ASTM standards indicate a maximum blend ratio; however, lower blends can also be certified. Every SAF batch needs to be analysed and certified at the point of origin (where it is blended). Only after being certified can the fuel be considered and treated in the same way as any conventional jet fuel (i.e., being mixed in the airport fuel farm tanks). Therefore, an appropriate storage facility is required, where the blended batch can be stored separately from other batches until the certification has been completed[58].

Another key element to be considered regarding the SAF blending process is to find the suitable fossil blending component. As not only the pure SAF, but the final blend need to meet certain properties, the fossil blending component should have high aromatics content. While jet fuel standards do not require a minimum content of aromatics for fossil jet (ASTM D1655/DEF STAN 91-91), they (ASTM D7566) do establish a minimum content of aromatics of 8 per cent for blends containing SAF. As most SAF types (except FT-SKA) do not contain aromatics, the aromatics content in the fossil blending component needs to be at least 16 per cent for blend ratios of 50/50, in order to achieve at least 8 per cent aromatics content in the final blend to be certified (ASTM D7566).

The performance of these blended fuels has been tested and has already been demonstrated through several thousand commercial flights worldwide[59]. In addition, it is significant that there are currently three airports distributing alternative fuel to aircraft on a regular basis: alternative fuels are blended directly into the fuel farm and hydrants systems at Oslo and Stockholm airports; and SAFs are supplied to United Airlines flights at Los Angeles airport.

[57] RCQ - Refinery Certificate of Quality. CoA - Certificate of Analysis. CoQ – Certificate of Quality.

[58] Continuous blending systems, where blending is done at the pipeline directly, and not in a tank, cannot be used for SAF blending as the blended batch needs to be certified at the point of origin before coming into contact with any other batch. These systems are sometimes used for other biofuels like bioethanol because the only key parameter to ensure is the blend ratio; such systems cannot be applied to SAF.

[59] ICAO Environment: GFAAF - Aviation Alternative Fuel Live Feed. Retrieved from https://www.icao.int/environmental-protection/GFAAF/Pages/default.aspx

[60] From the above list, only Altair is currently producing SAF at a commercial scale on a regular basis. Neste did produce one batch of SAF at commercial scale. The rest are projects not yet in operation or not yet producing SAF. This list only includes projects for the technologies currently included in the ASTM D7655. Small purchases (batch) are not indicated (as extrapolated from several sources).

TABLE 5
Companies currently pursuing SAF production and off-take agreements. Source: adapted from ICAO CAAF/2-WP/10

Producer	Purchaser	Offtake production per year (million gal.)[61]	Offtake production per year (Mt)	Start/Length of agreement (years)
AltAir	United Airlines Gulfstream/World Fuel SkyNRG/KLM	5 N/A N/A	0.015 N/A N/A	2016 / 3 N.A. / 3 2016 / 3
AltAir/Neste	KLM/SAS/Lufthansa/ AirBP	0.33	0.001	N.A. / 3
Fulcrum	Cathay Pacific United Airlines Air BP	35 90-180 50	0.106 0.274-0.547 0.152	N.A. / 10 N.A / 10 N.A. / 10
RedRock	Southwest FedEx	3 3	0.009 0.009	N.A./N.A. N.A. / 7
Amyris/Total	Cathay Pacific	48 A350 deliveries at 10% blend		
SG Preston	Jet Blue	10	0.030	2019 / 10
Gevo		8	0.024	N.A. / 5
TOTAL		204.33 to 294.33	0.621 to 0.894	

Even though the number of production facilities is still limited for these new technologies, new plants are under development, as a result of government policies and the off-take agreements established between producers and airlines. The continuously growing number of projects and off-take agreements is a clear indicator that the SAF sector is rapidly growing and that it will continue developing. Table 5 below shows a list of companies pursuing SAF production at commercial scale as well as current off-take agreements.

A SAF refinery is a long term investment; therefore, longstanding strategies need to be considered in the decision concerning its implementation. The establishment of a new facility can only be made after a certain period of preparation, including ensuring the appropriate feedstock supply, the definition of the project and implementation and testing. This process could potentially take longer if the feedstock is new or not sufficiently known in the area.

[61] Million gal. = Million US gallons, Mt = Million US tons.

4. SUSTAINABLE AVIATION INDUSTRY IN TRINIDAD AND TOBAGO: FUEL AND FEEDSTOCK

For the purpose of this study, SAFs are defined as fuels derived from sustainable resources that generate lower carbon emissions than conventional fossil fuels based on a Life-cycle analysis (LCA). This study discusses sustainable fuels for two different aspects of the aviation sector:

- GSE - sustainable fuels for land transport operating within restricted airport grounds
- Aircraft - SAFs

4.1 SUSTAINABLE FUELS FOR GROUND SUPPORT EQUIPMENT

The most widely used sustainable fuels for land transport are ethanol and biodiesel dispensed as blends with gasoline and diesel fuels respectively. Electricity generated through renewable sustainable resources like wind, solar, and biomass can also qualify as sustainable fuel to power electric vehicles. These fuels are regulated under strict local and international quality standards, commercialized through established market mechanisms to offer optimal economic, social, and environmental benefits, and are a suitable option to power GSE vehicles.

4.2 SUSTAINABLE AVIATION FUELS

Contrary to sustainable fuels for GSE, SAFs are a fairly new concept for which markets have yet to mature into fair and competitive commercial platforms at local, regional, and global levels. SAFs will play an important role in meeting the industry's ambitious carbon emissions reduction goals, allowing airlines to reduce their CO_2 emissions, "ease their dependence on fossil fuels and enjoy benefits from increased energy supply diversification. Life-cycle greenhouse gas emissions from [SAFs] can be up to 80 per cent lower than traditional jet fuel"[62]. SAFs are drop-in synthetic fuels designed in such a way that their components and properties are close to those of conventional jet fuels.

The following are main requirements for SAFs:

- Can be safely mixed with conventional jet fuel
- Meet the same technical specifications as conventional jet fuel, in particular resistance to cold and high energy content (automotive bioethanol and biodiesel are different and are not suitable)
- Meet sustainability criteria such as life-cycle carbon reductions, limited fresh water requirements, no competition with food production and no deforestation[63]
- Qualify as drop-in, fully compatible, mixable and interchangeable fuel that uses the same distribution, storage, and supply infrastructure as conventional jet fuel, and does not require adaptation of aircraft or engines

Most importantly, SAFs have to comply with international and, in some countries, also national quality and safety regulations. Standard ASTM D4045 frames the process of approval for SAFs. For the specification of synthetic fuels for use in turbine engines, ASTM has created a specific standard, D7566, which includes a dedicated annex for each newly approved fuel pathway[64].

4.3 AVAILABLE FEEDSTOCK FOR CONVERSION INTO SUSTAINABLE AVIATION FUELS

From the list of approved pathways above, the FT- Synthetic Paraffinic Kerosene (SPK) process using GTL conversion technology seems a convenient choice for Trinidad and Tobago considering the current development of a GTL-FT plant for provision of cleaner burning fuels for the marine sector. Though plentiful and inexpensive in Trinidad and Tobago, natural gas is not a renewable resource. Nevertheless, there is a diversity of alternate natural resources in Trinidad and Tobago that could prove suitable for the provision of renewable sustainable CH_4 for conversion into BTL-SAFs.

The following chapter analyzes a variety of approved feedstocks for conversion into SAFs available in Trinidad and Tobago. Potential sources include agricultural products, algae, waste gases from industrial processes, and municipal solid waste (MSW).

4.3.1 AGRICULTURAL PRODUCTS

Three out of five of the pathways approved by ASTM for use in gas turbine engines include the use of different types of agricultural products as feedstock. Advances in the production of more affordable and environmentally SAFs favour the use of wastes and residues as feedstock.

Agricultural wastes, residues, non-food cellulosic material, lignocellulosic material, and MSW are a globally abundant, diverse, low cost resource with limited competition with food supply and

[62] IATA. Fact Sheet Alternative Fuels. Retrieved from http://www.iata.org/pressroom/facts_figures/fact_sheets/Documents/fact-sheet-alternative-fuels.pdf
[63] IATA. Fact Sheet Alternative Fuels. Retrieved from http://www.iata.org/pressroom/facts_figures/fact_sheets/Documents/fact-sheet-alternative-fuels.pdf
[64] ICAO Environment: Alternative Fuels: Questions and Answers. Retrieved from https://www.icao.int/environmental-protection/Pages/AltFuel-SustainableAltFuels.aspx

low carbon intensity[65]. Biofuels produced from wastes and residues receive more favourable incentives under the Renewable Fuels Standard and the California Low Carbon Fuel Standard[66] from the U.S., as well as under the European Union's Renewable Energy Directive 2009/28/EC[67]. In addition, such biofuels usually received lower carbon intensity values, offering greater CO_2 reductions increasing their environmental credentials and monetary value.

Sugar cane has been used as feedstock for the production of biofuels for many years. In Brazil, the crop has been used as the main feedstock to produce ethanol for land transport at large scales since the oil embargo of 1973. In order to qualify under sustainability certification criteria and avoid any claims of using food for fuel production, cane bagasse[68] has gained ground in recent years as the preferable feedstock for conversion into biofuels. No data is publicly available specifically evaluating the conversion of cane bagasse into SAFs. As with most other biomass like such derived from forestry or corn production, cane bagasse can theoretically be processed into renewable SAFs through gasification (syngas conversion) and transformed into liquid fuels through a BTL-FT conversion process. Unlike GTL fuels, BTL are sustainable fuels that use renewable methane derived from waste biomass (agricultural, forestry and municipal solid waste, etc.) for conversion into sustainable renewable naphtha, diesel, and jet fuel.

In the past, leading sugar cane producer Caroni 1975, held about 70,000 ha of sugar cane production in Trinidad and Tobago. After its closure in 2013, commercial sugar cane production ceased and today only about 10-15 ha are under cultivation mainly for the production of animal feed. The Sugarcane Seeds Centre also dedicates some land for research to improve crop management practices. Past experience on crop production and climatic conditions in Trinidad and Tobago do favour the production of sugar cane in Trinidad and Tobago. Yet limited land availability for agricultural practices and a decline on budgetary expenditure allocations to the agricultural sector cover the past decade can make cane bagasse an unsustainable feedstock for conversion into biofuels from economic, social, and economic perspectives.

Currently, Trinidad and Tobago has a total arable land of roughly 25,000 ha[69]. The following map illustrates the distribution of Trinidad and Tobago's arable land according to land use[70]:

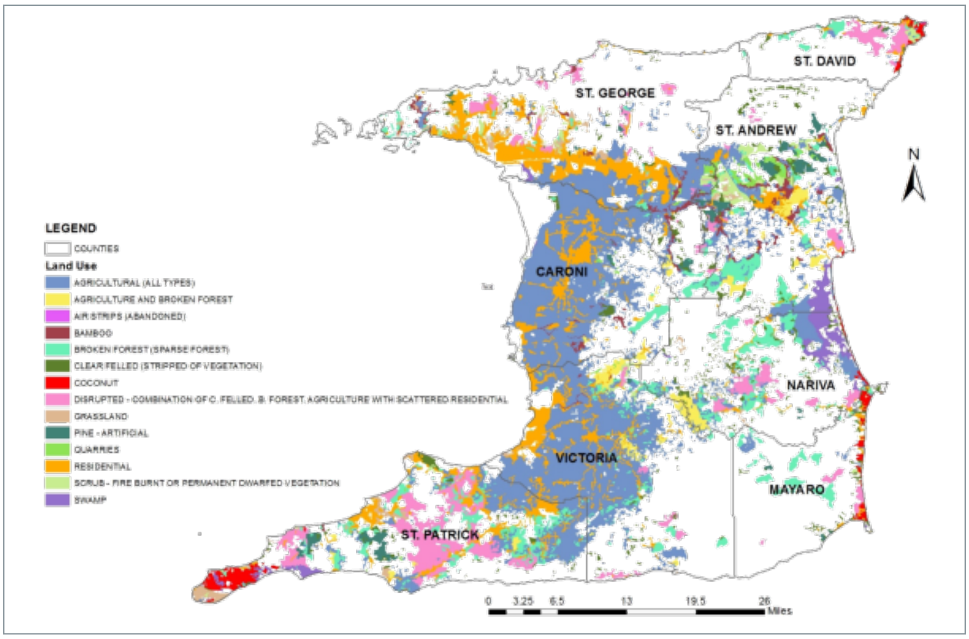


FIGURE 10
Land use by county in Trinidad, 2016[71]

[65] Michele Rubino. Cellulosic Ethanol: A Long Road to Success? Retrieved from http://www.biofuelsdigest.com/bdigest/2017/05/04/76408/7/
[66] California Energy Commission. Low Carbon Fuel Standard: Fuels and Transportation Division Emerging Fuels and Technologies Office. Retrieved from http://www.energy.ca.gov/low_carbon_fuel_standard/
[67] Official Journal of the European Union. Directives: Directive 2009/28/Ec Of The European Parliament And Of The Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC. Retrieved from http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009L0028&from=EN
[68] Cane bagasse is the milling by-product which remains after extracting sugar from the stalk.
[69] The World Bank. Trinidad and Tobago: Arable land (% of land area). Food and Agriculture Organization, electronic files and web site. Retrieved from http://data.worldbank.org/indicator/AG.LND.ARBL.ZS?locations=TT
[70] No map is publicly available for land use in Tobago
[71] Source: Rene Jordan. Land Use by County (Trinidad)

In general, for every tonne of sugarcane processed in the mill, around 190 kg of bagasse is generated[72]. One tonne of biomass will produce an estimated 1.25 oil barrels (bbl) of liquid fuel. Taking into account sugar cane yields at approximately 40 tonnes/ha and a total annual jet fuel consumption of 1,068,128 bbl for 2015 in Trinidad and Tobago, an estimated 11,180 ha[73] of arable land would need to be converted to sugar cane production to supply approximately 10 per cent of Biomass-to-Liquid Sustainable Aviation Fuel (BTL-SAF) from bagasse for the local aviation market. This pathway encourages the dedication of about 44 per cent of arable land to the cultivation of a single crop, potentially causing the degradation of natural resources commonly observed in monoculture cropping systems.

The use of cane bagasse as feedstock for SAFs could also trigger increased food security risks in Trinidad and Tobago. Local farmers produce a variety of subsistence crops and food products like fruits, legumes, and vegetables, enough to supply just eight per cent of the nation's staple food requirements[74]. The remaining 92 per cent of food products are imported[75], primarily from the U.S., placing the nation at a high food security risk. The production of cane bagasse for conversion into SAFs could displace the use of land from food to fuel adding further pressure to food security in the country. Furthermore, any biofuel produced under these conditions will be deemed unsustainable and commercially undesirable to airlines, making sales unfeasible.

Diminishing budgetary allocations to the agricultural sector by the GORTT can also contribute to making cane bagasse an unsustainable feedstock for conversion into SAFs. As illustrated on table 6 below, budgetary expenditure allocations by the National government to the Agricultural sector have been downward trending in the past years:

Trinidad and Tobago 's National Budgetary Expenditure Allocation Ministry of Agriculture, Land and Fisheries		
Year	**Allocation to Agriculture (billions TT$)**	**Share Percentage among Remaining Ministerial Allocations (%)**
2009	2.2	8.2
2010	1.3	3.6
2011	1.8	6.8
2012	1.9	6.6
2013	1.3	4.0
2014	1.3	3.8
2015	1.3	3.4
2016	0.8	2.0
2017	0.8	2.6

TABLE 6

Trinidad and Tobago Expenditure Allocation - Ministry of Agriculture, Land and Fisheries. Source: Ministry of Finance of Trinidad and Tobago

Insufficient investment in the sector has been accompanied by a progressive decline in arable land[77], a shrinking workforce, and outdated technology and infrastructure[78]. This makes the revival of the sector a more lengthy process requiring significant investment far beyond to what the nascent industry for SAFs can afford.

In order to produce at large scale and offer airlines competitive and reliable volumes of SAFs Trinidad and Tobago would need to import significant volumes of low-cost sustainable feedstock and invest sums of over a hundred million U.S. dollars in processing infrastructure. Yet, there is no assurance that even the most efficient production of SAFs in Trinidad and Tobago could produce a competitive renewable fuel when other producing countries are able to proclaim policy protecting local production.

4.3.2 ALGAE

"Compared to most agricultural products, algae are inherently more efficient solar collectors, use less or no land, [produce significantly higher yields per hectare under production,] and can be converted to liquid fuels using simpler technologies than cellulose"[79]. "Algae efficiently use CO2, and are responsible for more than 40 per cent of the global carbon fixation"[80]. Algae derived SAF is an approved pathway (HEFA drop-in fuel) for ASTM certification making them suitable for use on commercial flights.

For the past several years, numerous investigators and companies have focused on algae research for conversion into SAFs. The U.S. has been particularly active in algae research for biofuel applications in the past ten years. On December 15, 2016, the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy's Bioenergy Technologies Office announced a funding opportunity of up to US$8 million for innovative technologies and approaches to help advance bioenergy and bioproducts from algae, including aviation biofuels[81]. Airlines have also demonstrated interest in using drop-in SAFs derived from algae. As early as 2001, the U.S. Navy successfully flew a MH-60S Seahawk helicopter on a 50-50 blend of traditional and algae-based jet fuel. United Airlines flight 1403 became the first U.S. commercial flight powered in part by algae-based biofuel supplied by Solazyme[82]. In 2011, Continental Airlines made history with the first-ever test flight of a commercial jet in the U.S. powered with a blend of algae-based fuel and conventional jet fuel[83].

[72] Salman Zafar. Biomass Resources from Sugar Industry. BioEnergy Consult. Retrieved from http://www.bioenergyconsult.com/tag/bagasse/
[73] Sugarcane Feeds Centre, Ministry of Agriculture, Land, and Fisheries of TT, personal communication, February 23, 2017
[74] New Agriculturist. Country profile - Trinidad and Tobago. Retrieved from http://www.new-ag.info/en/country/profile.php?a=3023
[75] Central Statistical Office - MPD, personal communication, December 10, 2016
[76] Trinidad and Tobago Ministry of Finance. Budget Statements 2012 through 2016. Retrieved from http://www.finance.gov.tt/category/budget-statement/
[77] Arable land (in hectares) includes land defined by the Food and Agriculture Organization as land under temporary crops (double-cropped areas are counted once), temporary meadows for mowing or for pasture, land under market or kitchen gardens, and land temporarily fallow. Land abandoned as a result of shifting cultivation is excluded. http://www.tradingeconomics.com/trinidad-and-tobago/arable-land-hectares-wb-data.html
[78] Ministry of Agriculture, Land, and Fisheries, personal communication, October 12, 2016
[79] Dismukes GC, Carrieri D, Bennette N, Ananyev GM, Posewitz MC. Aquatic phototrophs: efficient alternatives to land-based crops for biofuels. Curr Opin Biotechnol. 2008;19(3):235–240. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/18539450
[80] Michael Hannon, Javier Gimpel, Miller Tran, Beth Rasala, and Stephen Mayfield. Biofuels from algae: challenges and potential. US National Library of Medicine National Institutes of Health. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3152439/#R9
[81] National Algae Association. 2016 Algae Year in Review – Nothing has Changed. Retrieved from http://www.nationalalgaeassociation.com/2016_Algae_Year_in_Review1.pdf
[82] Algae Biomass Organization, All About Algae. Algae Fuels: Renewable Aviation Fuel. Retrieved from http://allaboutalgae.com/
[83] Jon Hilkevitch. Continental Airlines flight is first in U.S. to use biofuel. Los Angeles Times. Retrieved from http://articles.latimes.com/2011/nov/11/business/la-fi-biofuel-airlines-20111111

Besides to its suitability as feedstock for the production of alternative transport fuels, the processing of algae can also yield a variety of co-products applicable for use in other sectors like plastics, chemicals, lubricants, fertilizers, dietary supplements, animal feed, pharmaceuticals and cosmetics. Most, if not all of these commercial channels, offer a higher value market price for algae co-products than the biofuels market. Therefore, biofuels derived from algae cannot compete with alternative markets. Several companies switched their business model from biofuel production to the commercialization of algae derived co-products for alternative markets to increase economic gains and reduce investment risks. LiveFuels, Aurora Algae, and Solazyme (renamed to TerraVia after the switch), are examples of private entities that turned their business from selling algae co-products for biofuel processing to supplying sustainable feedstock for conversion into plastics, cosmetics, food products and animal nutrition ingredients[84]. Furthermore, most companies looking to start a business in algae production today build their business plan with alternative markets in mind as opposed to SAFs for transport[85].

Some research on industrial applications for algae has been conducted in Trinidad and Tobago, especially using Sargassum as a feedstock. Sargassum is a genus of brown algae which are invasive in Trinidad and Tobago. Given the right conditions, this alga reaches Trinidad and Tobago in excess volumes and makes a thick cover on its beaches, which negatively impacts ecosystems as well as the fisheries industry. While several academic institutions in Trinidad and Tobago and the Caribbean region have found feasible applications of Sargassum algae for animal feed, cosmetics, and food products, the unpredictability of the occurrence and supply of seaweed makes industrial applications a high risk venture. "No national or regional research [is being] conducted on the investigation of marine algae for alternate fuels for aviation"[86].

4.3.3 WASTE GASES FROM PETROCHEMICAL PRODUCTION

CO_2 rich pressure swing absorption (PSA)[87] tail gas from the large-scale commercial synthesis of hydrogen (H_2) for use in oil refineries is a potential feedstock for the production of low cost, low carbon fuels and chemicals, including SAFs. LanzaTech is a pioneer in this sector, offering applicable and proven processing technology to convert gases containing CO and/or CO_2 plus hydrogen H_2 into renewable liquid fuels. The company is currently in the process of "building its first commercial-scale units utilizing steel mill gas to begin operation in 2017 with planned capacities of 60,000 and 150,000 tonnes per year"[88].

Considering Trinidad and Tobago's crude oil refining capabilities, the availability of PSA tail gas resulting from oil refining processes at Petrotrin's was considered[89]. The following table 7 illustrates the chemical composition and available volumes of tail gas from the company's steam methane reformer on the H_2 plant used for the processing of liquid fuels for transport:

Unfortunately, both available volumes and the chemical composition of the PSA tail gas reported by Petrotrin are unsuitable for conversion into renewable jet fuel under existing processing technology. A flow rate of 6,538 - 16,346 Nm3/hr is about half of the scale suitable to allow reasonable economic returns and a CO stream of 4.47mol per cent is too diluted; the process requires CO volumes of at least 10 mol per cent[91].

Item	Unit	Waste gas
Flowrate	Nm^3/hr	6,538 - 16,346
Flowrate	mmscf/d	5.86 – 14.64
H_2	%	25.83
CO	%	4.47
CO_2	%	55.95
CH_4	%	12.41
N_2	%	0.04
H_2O	%	1.3

TABLE 7

PSA tail gas - Petrotrin. Source: Petrotrin

[84] Katie Fehrenbacher. Solazyme Ditches Biofuels (& Name) in a World of Cheap Oil. Fortune Tech. Retrieved from http://fortune.com/2016/03/16/solazyme-terravia-ditches-biofuels/
[85] National Algae Association, personal communication, February 1, 2017
[86] Institute of Marine Affairs in TT, personal communication, January 30, 2017
[87] PSA is a technology used to separate some gas species from a mixture of gases under pressure according to the species' molecular characteristics and affinity for an adsorbent material. One of the primary applications of PSA is in the removal of CO_2 as the final step in the large-scale commercial synthesis of H2 for use in oil refineries and in the production of ammonia.https://swana.org/Portals/0/Awards/2012Noms/Landfill_Gas_Control_silver.pdf
[88] LanzaTech. LanzaTech Abstract: Innovations for a Carbon Smart Future. Retrieved from http://co2-chemistry.eu/media/files/2016/Abstracts/16-09LanzaTechCO2utilizationAbstract.pdf
[89] Petrotrin, personal communication, September 28, 2016
[90] Petrotrin, personal communication, September 28, 2016
[91] LanzaTech, personal communication, October 27, 2016

4.3.4 MUNICIPAL SOLID WASTE (MSW)

MSW can be converted into liquid fuels for land, air, and marine transport. Landfill gas (LFG) is captured, cleaned, and the CH4 portion is converted to renewable sustainable fuels through the BTL-FT process, the same conversion process used for the production of GTL-FT fuels but replacing natural gas with renewable sustainable CH_4.

LFG is composed of roughly 60 per cent CH4, 40 per cent CO_2, and a small amount of non-methane organic compounds[92]. Consequently, its conversion into BTL fuels offers not only emissions reductions in PM, NOx and CO common to the GTL-FT process, but also reductions in CO_2 and CH4from avoided emissions from the capture and use of LFG as feedstock. The processing of LFG into BLT fuels can greatly contribute towards Trinidad and Tobago's efforts to comply with their declared INDC to unconditionally reduce public transportation CO_2-equivalent (CO_{2e}) emissions by 30 per cent[93] compared to 2013 levels by December 31, 2030[94].

Initiatives like this one that offer significant reduction in GHG emissions can also qualify as a Clean Development Mechanism (CDM) project generating Certified Emission Reduction units (CERs) which may be traded in emissions trading schemes improving the overall economic viability of the project. Certainly, the use of landfill gas (LFG) for the production of SAFs will further contribute towards the total number of CERs generated.

Two prominent processes have been proven effective for the production of SAFs from MSW:

- MSW > Land fill gas capture > Anaerobic Digestion > Upgrading of Biogas into Biomethane > Refining of Biomethane into SAFs (FT-SPK)
- MSW > Gasification- Syngas Generation > Upgrading of Syngas > Refining of Syngas into SAFs (Syngas to gasoline plus or STG+, FT-SPK)

These pathways have not been proven at large scale yet, but the starting point of initiatives currently under development rely on having a more advanced waste management system in place than any currently under operation in Trinidad and Tobago. ENVIA Energy's GTL plant for example, utilizes MSW from Waste Management's East Oak landfill site in Oklahoma City[95]. The East Oak landfill is already equipped with technology to capture and clean LFG facilitating the economic viability of converting MSW into GTL fuels.

In 2015, ARCADIS delivered a study proposing a strategic plan for solid waste management in Trinidad and Tobago[96]. The study recommends the development and implementation of an action plan for a comprehensive Environmental Management System (EMS) for all existing disposal sites. It also recommends the installation of infrastructure at all sites to monitor, collect, and flare LFG, as well as undertaking a detailed feasibility study for waste to energy options.

Any consideration for the conversion of MSW into BTL-SAFs should be taken only after the GORTT develops and approves enabling policy to upgrade the nation's waste management system. Aside from the lack of infrastructure to capture LFG, existing volumes of MSW in Trinidad and Tobago do not provide enough CH4 for the production of significant volumes of BTL-SAFs to fulfil local market demand. Nevertheless, an ambitious scheme for collection of organic waste separated from general MSW from residential, industrial and commercial producers, in parallel with an extensive public campaign on waste classification and recycling could help improve available local volumes of recoverable renewable CH4 for BTL-SAF production.

[92] U.S. EPA. Landfill Methane Outreach Program (LMOP): Basic Information about Landfill Gas. Retrieved from https://www.epa.gov/lmop/basic-information-about-landfill-gas

[93] CO_{2e}

[94] Trinidad and Tobago. Intended Nationally Determined Contributions Under the United Nations Framework Convention on Climate Change. Retrieved from http://www4.unfccc.int/Submissions/INDC/Published%20Documents/Trinidad%20and%20Tobago/1/Trinidad%20and%20Tobago%20Final%20INDC.pdf

[95] Velocys. Envia Energy. Retrieved from http://www.velocys.com/projects_envia_energy.php

[96] Arcadis. Solid Waste Management Strategic Plan for TT, 2051 (not yet published).Retrieved through personal communication with Trinidad and Tobago Solid Waste Management Company.

One million tonnes of MSW generates an estimated 460,000 cubic feet (ft3) of LFG a day[97], from which 60 per cent or 260,000 ft3/day approximately is renewable CH4[98]. That volume of CH4 will generate an estimated 25 barrels per day (bpd) of BTL-SAF[99]. Table 8 below shows data obtained by ARCADIS' investigative team on estimated accumulated volumes of MSW for the three largest landfills in Trinidad and Tobago. It also illustrates estimated recoverable CH4 from LFG and approximate resulting volumes of BTL-SAF:

Landfill	Existing MSW Volumes From 1989 To 2004 (tonnes)	CH4 Potential Volumes (ft3)	CH4 Potential Volumes (ft3)
Beetham	5,506,011	1,519,659	138
Forest Park	2,678,314	739,215	67
Guanapo	1,745,015	481,624	44
TOTAL	9,929,340	2,740,498	249

TABLE 8

MSW volumes in Trinidad and Tobago. Source: ARCADIS[100]

The BTL-FT process produces three main sustainable drop-in fuels: naphtha, diesel, and jet fuel. There are two most common output scenarios based on process configurations for jet fuel production:

- BTL Fuel Scenario A: 65% jet and 35% naphtha
- BTL Fuel Scenario B: 45% jet, 30% naphtha, and 25% diesel

Jet fuel demand at PIARCO International Airport for 2015 totalled 1,062,128 oil barrels of conventional jet A-1 fuel or a total of 2,910 bpd. Table 9 below shows the share of the jet fuel market that could potentially be supplied by BTL-SAFs form existing volumes of MSW in Trinidad and Tobago:

BTL-SAF Scenario A: 65% jet and 35% naphtha			
Biomass-to-Liquid Fuel	**Output %**	**bpd**	**market share %**
Sustainable Aviation Fuel	65	161	5.5
BTL-SAF Scenario B: 45% jet, 30% naphtha, and 25% diesel			
Biomass-to-Liquid Fuel	**Output %**	**bpd**	**market share %**
Sustainable Aviation Fuel	45	112	3.8

TABLE 9

Potential BTL-SAF Local Market Share

Results illustrated on table 4 show that the conversion of existing volumes of MSW in Trinidad and Tobago will not make a significant contribution to help reduce GHG emissions from the aviation sector. Furthermore, calculations assume that all three major waste sites in Trinidad and Tobago are upgraded to advanced engineering and equipped with LFG capture technology which is perhaps not realistic in the short to medium term. Therefore, even after the introduction of advanced engineering into waste management practices and the separation of organic waste at the source of origin, additional volumes of MSW might need to be sourced from neighbouring nations to provide enough renewable CH4 to supply local and regional aviation industries with SAFs. If the GORTT takes initiative to tackle the prevailing social and environmental negative impacts caused by current MSW management practices, the use of LFG for conversion into SAFs could add an unforeseen income stream further helping justify investment costs for the introduction of advanced landfill engineering infrastructure.

[97] Depending on the life of the project (LFG capture), moisture content of waste, and physical characteristics of the site, a landfill can generate such volumes of LFG for about 20 to 50 years.
[98] Emerging Fuels Technology, personal communication, October 10, 2016.
[99] For the purpose of this study, the definition of the term renewable GTL fuel is a gas-to-liquid fuel produced from CH4 derived from renewable resources.
[100] ARCADIS. Solid Waste Management Strategic Plan for TT, 2051 (not yet published).Retrieved through personal communication with Trinidad and Tobago Solid Waste Management Company.

4.3.5 SUMMARY

The following Table 10 offers a summary of feedstocks previously considered as potential sources for conversion into SAFs in Trinidad and Tobago:

Stage	Source	Quantity/Quality	Risks	Opportunity
Agricultural Products	Cane bagasse	Insufficient for scale production	• Monoculture: environmental degradation, food security • Economic: single feedstock increases risk	When mixed with other sources of renewable CH4, it could positively contribute to the deployment of SAFs in the long term
Algae	• Sargassum • Other varieties	Insufficient for scale production	• High CAPEX • Higher valued product on alternative markets distorts price competitiveness	Explore once global jet fuel prices become competitive with alternative markets for algae co-products
Waste Gases from Petrochemical Production	PSA tail gas	Insufficient volumes for scale production Gas quality unsuitable for current processing technology	N/A	Re-evaluate potential when applicable technology is commercially available to process existing tail gas at lower CO concentrations. Limited volume might still present a barrier to economic viability.
Municipal Solid Waste	Renewable CH4 from LFG	• Insufficient for scale production • Inadequate infrastructure for LFG capture	Economic: insufficient volumes of feedstock do not justify investment in upgrading landfill management practices	Consider the use of renewable CH4 for processing into SAFs as an additional revenue stream to justify investment in engineered waste management

TABLE 10

Summary of Assessed Feedstocks for Conversion into SAFs

5. FUTURE OPPORTUNITIES FOR SUSTAINABLE AVIATION FUELS IN TRINIDAD AND TOBAGO

The availability of the right quantities of locally sourced sustainable feedstock is not the only factor affecting the feasibility for deployment of SAFs in Trinidad and Tobago. Even if Trinidad and Tobago imported feedstock to fulfil volume requirements for the production of SAFs using current technology, distortions on pricing due to local policy enacted by competitors can influence the export market, making the initiative economically unviable.

Global markets for SAFs are not mature, the fuel is still priced at a premium, sales are currently viable because local policy helps bring prices to parity with conventional jet fuel, and protectionism remains a plausible measure nations can take to aid in the growth of this nascent industry. In the U.S. for example, under the Renewable Fuel Standard Program (RFS), specific SAFs pathways qualify to generate renewable identification numbers (RINs). These credits allow producers to compete on a level playing field with conventional jet fuel prices in local markets in the U.S. For nations like Trinidad and Tobago that need to find export markets where to place excess production of SAFs, these types of local policy result in unfair price competition.

ICAO and its Member States' current work on a global Market Based Measures (MBM) scheme targets potential distortions on the future global market for SAFs to avoid inequities on price competition. The global MBM scheme will be implemented in the form of the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), and it will go through pilot testing from 2021 through 2023. The first phase of implementation is scheduled to run from 2024 through 2026, and the second phase from 2027 through 2035. The success of the CORSIA could allow smaller nations like Trinidad and Tobago to compete in a level playing field for the commercialization of SAFs.

5.1 BIOMASS-TO-LIQUID SUSTAINABLE AVIATION FUEL

When the scenario changes and global commercialization of SAFs has matured into fair markets, Trinidad and Tobago could play an important role as a major regional supplier of SAFs. Trinidad and Tobago is already a major supplier of fossil fuels to many neighbouring island states, and the Nation holds about 108 years' experience in the production of commercial hydrocarbons. Trinidad and Tobago is currently a major exporter of liquefied natural gas with four trains capable of producing 15.1 million tons per annum (MTPA), and it is the world number one exporter from a single site of ammonia (10 Plants with 5.2 MTPA capacity) and methanol (7 plants at 6.5 MTPA capacity) . The country is equipped with a professional workforce with ample experience handling liquid fuels as well as established and reliable production and supply chains.

In addition, NETL's GTL-FT plant currently under construction at Pointe-A-Pierre represents an opportunity for the GORTT to begin testing the country's capability to produce FT advanced alternative fuels, and become a future strategic supplier of BTL-SAFs in the Caribbean region. NETL expressed genuine interest in developing a business plant to produce BTL-SAFs in collaboration with the GORRT given an available market[101]. The GORTT's support to the development of this new industry today ensures the future availability of a professional workforce knowledgeable on the BTL-FT production process and supply chain including feedstock logistics, fuel conversion and scale up, fuel testing and evaluation, storage and delivery, and commercialization to the end user. In the next 3 to 10 years, Trinidad and Tobago can also address existing challenges on availability of renewable CH4 for the production of SAFs through the following measures:

a) Exploring the idea of updating the nation's waste sites to engineered advanced landfills to allow for the capture of LFG for use as an affordable local source of renewable feedstock
b) Evaluating supplementing volumes of existing waste biomass, including MSW, with imports from, and cooperation with, neighbouring nations
c) Developing a specific route for the collection of organic residential and industrial waste as well as agricultural waste separately from MSW collection routes
d) Revising and modifying existing policy on the handling and disposal of waste from industrial and commercial partners to ensure selective disposal of the organic portion
e) Developing and launching capacity building workshops and training sessions on recycling and organic waste separation for the general public, and academic and public institutions

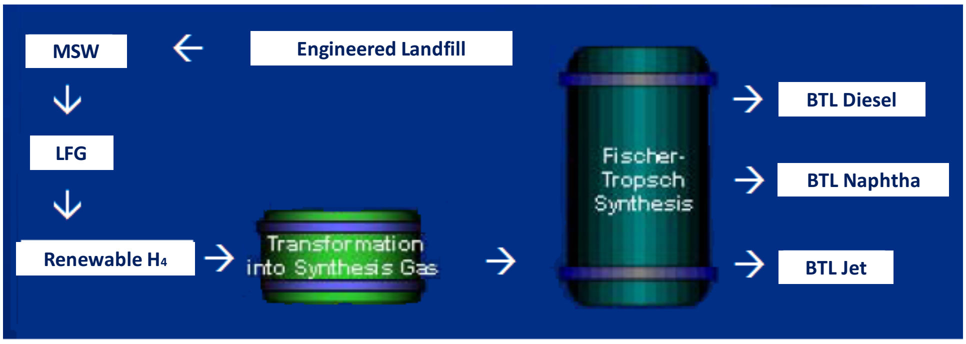
[101] NiQuan Energy, personal communication, October 20, 2016.

5.1.1 PROCESSING TECHNOLOGY

The BTL-FT conversion process for the production of SAFs uses the same processing technology than the one applied by NETL at their GTL-FT processing plant. The main difference is that because the sourcing of the feedstock is not from fossil reserves but rather from natural resources, the CH4 usually needs a more stringent cleaning process than natural gas. That is easily handled through well-established scrubbing techniques already incorporated into the processing method[102].

GTL-FT synthesis is a "well-known and established catalytic chemical process named after the original German inventors, Franz Fischer and Hans Tropsch in the 1920s.[...] Since then, many refinements and adjustments to the technology have been made, including catalyst development and reactor design"[103]. EFT is one of the world's foremost authorities on FT and related synthesis. The following Figure 11 illustrates key BTL-FT technology components:

FIGURE 11
Key technology components for BTL-FT synthesis



It is important to clarify that this technology offers the possibility to adjust output volumes of drop-in renewable sustainable diesel, naphtha, and jet fuel to market conditions. Output ratios between these three BTL fuels can be adapted to respond to price fluctuations with no significant investment in processing technology, allowing producers to maximize profits. As drop-in fuels, the transport, storage, and delivery are handled with the same infrastructure currently used for the commercialization, transport, and use of conventional diesel, naphtha, and jet fuel. NETL is basing their business model partly on this flexibility and diversification of fuel outputs to minimize investment risks.

Though there are additional processing technologies for the production of SAFs. BTL-FT and HEFA conversion processes are most prominent, both tested beyond lab or pilot scale[104]. The HEFA process uses vegetable oils for processing, a more expensive feedstock than those derived from waste biomass. As expressed earlier in this chapter, the BTL-FT process is suitable for Trinidad and Tobago not only because of the economic viability of the feedstock but also because the NETL GTL-FT plant will come under commission soon, bringing an experienced workforce and business model to Trinidad and Tobago. After a consistent and economically viable source for renewable feedstock is identified, Trinidad and Tobago can transition from GTL to BTL-FT fuel production for the transport sector including aviation, marine, and land.

5.1.2 EMISSIONS

There is no research publicly available on the LCA of BTL-SAFs. Qatar Airways is running a five year project evaluating emissions from GTL jet fuel made from natural gas at a 15 per cent blend mix with conventional jet fuel. Results are not available yet. Unlike Qatar Airways' LCA evaluations, the LCA for BTL-SAFs should also include further considerations in GHG emissions reductions from avoided CH4 emissions from landfills[105].

[102] Emerging Fuels Technology, personal communication, October 10, 2016.
[103] U.S. Department of Energy National Energy Technology Laboratory. Fischer-Tropsch Synthesis. Retrieved from https://www.netl.doe.gov/research/coal/energy-systems/gasification/gasifipedia/ftsynthesis
[104] William Greenbaum. Alternative Jet Fuels. Stanford University. Retrieved from http://large.stanford.edu/courses/2012/ph240/greenbaum1/
[105] Qatar Airways Group, personal communication, December 1, 2016.

An LFG collection system will capture roughly 60 to 90 per cent of the CH_4 emitted from the landfill, depending on system design and effectiveness[106]. As noted previously, one million tonnes of CH_4 are equivalent to emissions of 28-36 million tonnes of CO_2[107]. Therefore, the potential of BTL-SAFs to reduce CO_2e emissions is significant and will offer airlines much greater environmental credentials than SAFs processed from most vegetable oils or sugars.

The Environmental Protection Agency (EPA) in the U.S. has conducted several studies on waste-to-energy (WTE) projects evaluating GHG reductions from avoided methane emissions from landfills due to the collection, flaring and combustion (power generation) of LFG. "The GHG reductions associated with these three factors more than offset WTE fossil-based CO_2 emissions from combustion of plastics and other fossil fuel based MSW components. The LCA results in an approximate one ton reduction in GHG emissions for every ton of MSW combusted based on national averages as inputs"[103]. The following Figure 12 illustrates testing results:

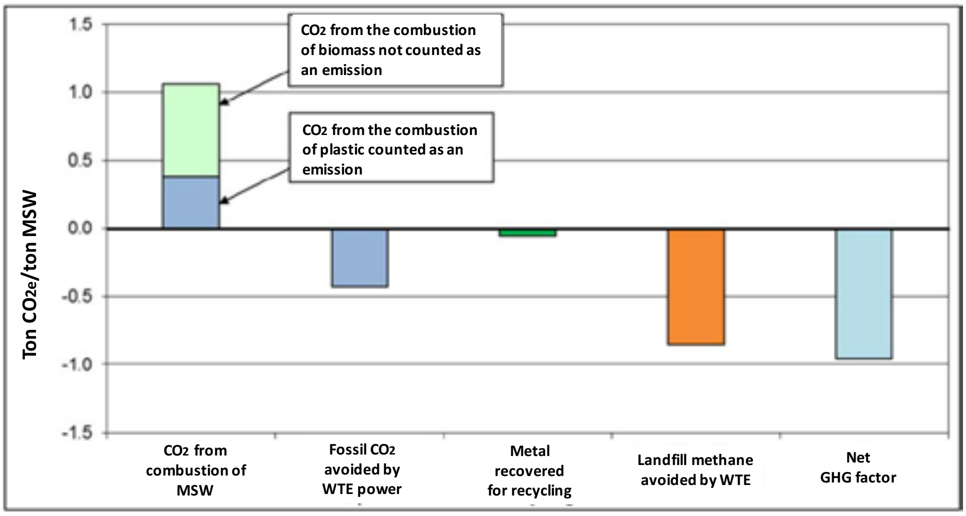


FIGURE 12
Waste to energy LCA testing results[108]

In the BTL conversion process, renewable CH_4 is used directly as feedstock for the production of SAFs; none is used for power generation. Therefore, the LCA for BTL-SAFs made from LFG will not include emission reductions resulting from the combustion of MSW depicted on the first and second bar lines on Figure 12. Nevertheless, the illustration offers interesting information on CO_2e from avoided CH_4 emissions which will be accounted for on LCA calculations. The best way to know with accuracy GHG emissions reductions from the burning of BTL-SAFs is by conducting a targeted LCA.

5.1.3 SUPPLY CHAIN

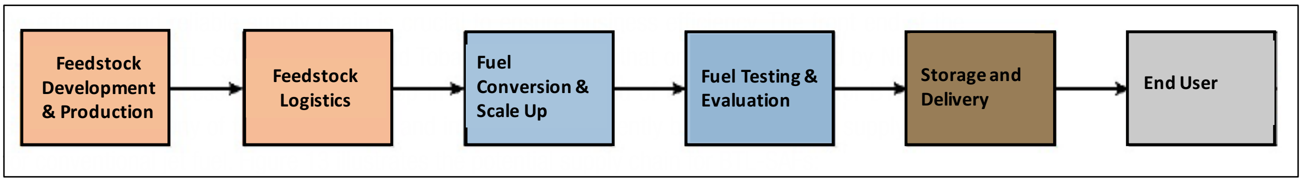


FIGURE 13
Supply chain for BTL-SAFs

[106] T. Michaels. "The 2014 Erc Directory of Waste-To-Energy Facilities." The Energy Recovery Council. Retrieved from http://energyrecoverycouncil.org/wp-content/uploads/2016/01/ERC_2014_Directory.pdf

[107] U.S. EPA. Understanding Global Warming Potentials. Retrieved from https://www.epa.gov/ghgemissions/understanding-global-warming-potentials

[108] T. Michaels, I. Shiang. 2016 Directory of waste-to-energy facilities. Energy Recovery Council. Retrieved from http://energyrecoverycouncil.org/wp-content/uploads/2016/06/ERC-2016-directory.pdf

The companies mentioned on the following possible scenario of how the supply chain for BTL-SAFs would look like in Trinidad and Tobago have not offered their consent to take part in this supply chain; they are used as mere examples of what could be achieved in Trinidad and Tobago using existing resources:

a) Feedstock Development and Production: with its ample experience in the handling natural gas, the NGC sources renewable resources from agricultural producers, SWMCOL, and foreign partners for the production of renewable CH4.
b) Feedstock logistics: the renewable CH4 is sent to Phoenix Park Gas Processors Limited (PPGPL) to remove any heavy condensate liquids, along with the removal of heavier hydrocarbons (Ethane C2H6, Propane C3H8 and Butane C4H10). Once this is achieved, the light hydrocarbons (predominantly CH4) are sent to the downstream users via a NGC distribution station, the GTL facility being one of them. Once the gas enters the Petrotrin Compound at Pointe-A-Pierre (GTL facility located within this area), the gas goes to a final gas scrubber to remove any final traces of condensate before entering the GTL plant for processing. Listed below are additional inputs and corresponding sourcing agencies:
    - Water from the Water and Sewerage Authority of Trinidad and Tobago (WASA), to generate steam, maintain cooling water system and fire water reserves,
    - Electricity from The Trinidad and Tobago Electricity Company (T&TEC),
    - Nitrogen from Industrial Gas Limited (IGL) for the purpose of purging the GTL plant start-up and as an inert gas for storage tanks.
c) Fuel Conversion and Scale up: NETL handles the conversion of renewable CH4 into BTL-SAFs.
d) Fuel testing and Evaluation: before the product is transferred to the customer, NETL conducts fuel quality testing and evaluation utilizing their own laboratory facilities. Afterwards, Petrotrin is responsible for conducting additional fuel quality control tests much as they do for conventional jet fuel. In both steps of the supply chain, tests will be verified by an independent inspector before the product reaches end users.
e) Storage and Delivery: Petrotrin takes upon the supply chain role as GTL jet fuel distributor responsible for storage and delivery much as they do today with conventional jet fuel. Technically, as a drop-in fuel, GTL jet fuel could be handled using existing infrastructure. Whether or not there will be a need for separate storage tanks and delivery equipment will be determined by policy ruling the use of SAFs in Trinidad and Tobago. If a blend of SAFs is an obligation for all airlines operating in and out of Trinidad and Tobago, no additional infrastructure will be required. If the use is dictated as voluntary, the distributor would need to handle the blend separately from the neat jet A1 fuel.
f) End users: all airlines operating to and from Trinidad and Tobago's airports are end users if policy dictates that the use of SAFs is obligatory, only some if the use is voluntary.

The design of this supply chain will have to be revisited in future scenarios when Trinidad and Tobago finds it economically viable to partake in the production of SAFs. The illustration above is just to demonstrate that many of the potential parties that would be involved in the supply chain for BTL-SAFs are already operating in Trinidad and Tobago.

5.2 CERTIFICATION FOR BIOMASS-TO-LIQUID SUSTAINABLE AVIATION FUEL

5.2.1 QUALITY CERTIFICATION

Currently, Petrotrin is responsible for conducting quality control tests for jet fuel[109]. Results are then verified by an independent inspector before the fuel reaches end users. Petrotrin adopted the ASTM D1655 quality standard, Standard Specification for Aviation Turbine Fuels, to ensure compliance and offer a high quality product to airlines. "The Trinidad and Tobago Bureau of Standards has not done any work in the area of aviation fuels and it is not on [their] current work plan for 2017"[110]. It is therefore safe to assume that Petrotrin will adopt standard ASTM D7566, Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons, for quality certification of GTL jet fuel.

[109] Petrotrin, personal communication, September 28, 2016.
[110] Laboratory Services Division at the TTBS, personal communication, December 16, 2016.

5.2.2 SUSTAINABILITY CERTIFICATION

The environmental sustainability of SAFs must be confirmed through a sustainability analysis to ensure the fuel, for example, does not contribute to deforestation, competes with food, or causes other unsustainable side-effects.

Several existing voluntary and regulatory sustainability standards and frameworks are applicable to SAFs, in particular: the Roundtable on Sustainable Biomaterials (RSB) standard, the sustainability framework for the production of bioenergy from the Global Bioenergy Partnership (GBEP), the International Organization for Standardization's ISO 13065:2015 (Sustainability frameworks for the production of bioenergy) as well as the regulatory standards in the European Union's Renewable Energy Directive (EU-RED) and the U.S. Renewable Fuel Standard.

The RSB certification scheme is a robust and comprehensive standard covering a wide and diverse range of criteria among existing biofuel certification schemes. The aviation sector is particularly interested in sourcing SAFs that have been certified under a robust set of principles and criteria and that leave no room for poor environmental and social practices. Just recently, United Airlines has announced the use of commercial scale volumes of certified SAFs on flights departing from Los Angeles International Airport and has agreed to purchase 15 million gallons of SAFs from AltAir Paramount over a three-year period. AltAir Paramount is currently undergoing the certification process for sustainable practices under the RSB standard[111]. Considering the airlines' interest in ensuring that SAFs result in positive environmental and social impacts, the certification process might turn out to be remarkably demanding.

A recent study funded by the International Aviation Transport Association (IATA) concluded that the certification process for sustainable practices in the production of SAFs could act as a barrier limiting the volumes of certified biofuels in the market[112]. This is true for all transport biofuels, including SAFs. The following matters are described as areas that need further work to enable the sustainability certification process to a wider audience:

- The lack of further flexibility and adaptation of some environmental and social indicators to local conditions may act as a barrier to the process of certification.
- The failure to provide an established and sizeable market or deliver a price premium for certified SAFs is limiting the wider adoption of sustainability standards in biofuel supply chains.
- The certification process for sustainable practices is simpler for biofuel producers who rely on non-agricultural or non-forest wastes for their production processes.
- Compliance difficulties arise from the lack of auditor experience certifying against a new certification scheme with unique social requirements.

Any future considerations for the deployment of SAFs in Trinidad and Tobago will need to address all these gaps to motivate producers' participation in the sustainability certification process.

[111] United Airlines PRNewswire. United Airlines Makes History with Launch of Regularly Scheduled Flights Using Sustainable Biofuel. retrieved from http://newsroom.united.com/2016-03-11-United-Airlines-Makes-History-with-Launch-of-Regularly-Scheduled-Flights-Using-Sustainable-Biofuel

[112] IISD. Quantifying the Challenges of Adopting Sustainability Criteria for Biofuel Production. International Institute for Sustainable Development. Retrieved from http://www.iisd.org/library/quantifying-challenges-adopting-sustainability-criteria-biofuel-production

6. GROUND SUPPORT AIRSIDE EQUIPMENT

Airport Ground Support Equipment (GSE) fleets are uniquely suited for alternative fuel vehicles (AFV) for many reasons:

- They travel contained routes conducive to central fuelling.
- Airport fleets typically travel many miles each day and consume large quantities of fuel, which can result in significant fuel cost savings.
- Their duty cycles include long idle times and frequent stops. AFVs can help these fleets reduce engine wear, pollution, and fuel costs.
- GSE often stays in operation for decades, providing long-term air quality benefits and cost savings, since incremental expenses can be amortized over many years.
- AFVs can help fleets improve the image of airports by reducing the exposure of travellers to noxious ground-level emissions from gasoline and diesel vehicles. This pollution is often trapped in curbside environments by overhangs, awnings, and buildings.
- Airport fleets are highly visible to the traveling public, providing the opportunity to educate the public to the benefits of AFVs and their broad proven applications, and to provide corporate stewardship in the community.

In the U.S., Boston Logan International Airport, Denver International Airport, and Los Angeles International Airport among others, have already incorporated the use of AFVs in their GSE fleets powered by CNG, liquefied natural gas, propane, and electricity. Furthermore, they are using AFVs on buses, shuttles, pick-ups, and light duty vehicles transporting passengers and cargo to airport grounds. All three airports reported long term economic gains from the incorporation of AFVs as well as increased customer acceptance based on environmental care. Though success is measured individually, results are encouraging for other airports around the world to follow suit[113].

6.1 ALTERNATIVE FUELS FOR GROUND SUPPORT AIRSIDE EQUIPMENT IN TRINIDAD AND TOBAGO

The use of AFVs for GSE can also positively contribute to sustainable growth in the aviation sector in Trinidad and Tobago. Major stakeholders were interviewed to determine the different measures currently being taken or under development to reduce harming emissions form GSE.

The Airports Authority of Trinidad and Tobago has outlined a long term proposal to install a solar farm at PIARCO International Airport[114]. The sunny climate of Trinidad and Tobago offers significant potential for the harnessing of solar energy for power generation. Figure 14 below shows five roofs and one open field as potential sites where to install solar panels for optimal performance at PIARCO International Airport.

FIGURE 14
Location for Potential Installation of Solar Panels at POS Airport

[113] Clean Cities. "Clean Cities Alternative Fuels Information Series- Airports: Alternative Fuels Niche Market." Retrieved from http://www.afdc.energy.gov/pdfs/airportafvfleets.pdf
[114] Airports Authority of Trinidad and Tobago, personal communication, October 3, 2016

Electricity generation from solar power would be incorporated to the national energy grid to provide the airport, including GSE electric vehicles (EVs), and residential homes with renewable energy. The project goal is to "reduce 20 per cent of the current environmental pollutants generated by airport activities by 2020 with a major focus on GHG emissions"[115] . There are currently 74 GSE vehicles operating at PIARCO International Airport (excluding fire services vehicles). This small fleet will not justify overall investment costs to build a solar farm, but the use of EVs on GSE fleets will definitely help reach the project's goal faster.

Piarco Air Services Limited (PAS) owns two forklifts powered by CNG. Maintenance and fuel costs are significantly lower than for fossil fuel powered vehicles, so given the possibility to refuel in the north and south terminals at PIARCO International Airport, the company would seriously consider acquiring more CNG powered vehicles[116]. In addition, PAS can take advantage to the 15 per cent subsidy from the total purchase cost of CNG vehicles to update the fleet. CNG is not a renewable fuel and it offers limited sustainability credentials when compared with sustainable biofuels like BTL fuels and solar or wind power. For example, EVs fueled with renewable power offer much greater CO_2 emissions reduction than CNG powered vehicles. Yet investment to replace the current fleet by EVs and train maintenance staff would be greater for PAS than retrofitting existing vehicle to use CNG. As long are there are no penalties for emissions of CO_2 from GSE, PAS finds no incentive to invest in EVs. Therefore, PAS considers CNG a suitable alternative fuel to help reduce CO_2 emissions from GSE before they progressively transition to more sustainable fuels.

Swissport Trinidad and Tobago Ltd, PSA's competitor in the provision of GSE in Trinidad and Tobago airports, expressed a slightly different view on investment in EVs. The company recognizes that EVs can significantly lower fuel and maintenance costs and they are willing to invest in replacing most of their fleet and train their maintenance employees if the GORTT were to install a charging station on both terminals at PIARCO International Airport. Swissport is a global airport service provider with a much larger budget than PAS which allows more flexibility for long term planning. Currently, Swissport operates two of their forklifts on CNG and several of the warehouse fleet on liquefied petroleum gas. Maintenance and fuels costs are lower using CNG and liquefied natural gas but the lack of refuelling stations at the airport limits the number of vehicles that they can operate on alternative fuels[117].

6.1.1 TRANSITIONAL ALTERNATIVE FUELS

Both airport operators agree that the use of AFVs can not only offer economic benefits but also help curb environmental impacts from the use of fossil fuels. Unfortunately, a GSE fleet of 74 vehicles does not justify the major investment required to install a solar farm at PIARCO International Airport. Therefore, until the GORTT decides to execute such a project as part of a comprehensive plan to reduce GHG emissions from the overall energy sector, Trinidad and Tobago can only incorporate the use of CNG and biodiesel as transitional alternative fuels to minimize pollution from GSE until solar power is available and EVs can be incorporated into the fleet.

a) Compressed Natural Gas

In the short term, Trinidad and Tobago is already well equipped to assist GSE providers Swissport and PAS with the provision of CNG, presented by the GORTT as safer, cheaper, and cleaner alternative fuel.

CNG is not a sustainable fuel, however as described in Chapter 1, NGVs tested in the U.S. showed "13–21 per cent reduction in total GHG emissions (well-to-wheels) compared to new diesel and gasoline vehicles"[118]. After accounting for the global warming potential of all GHGs, CO_2 emissions are on average 95-99 per cent of total GHG emissions from a passenger vehicle[119].

For Trinidad and Tobago, CO_2 emissions reduction from the use of CNG have been calculated to be 30 per cent, a target declared by the MPD under the country's INDCs commitments recently presented to the UN[120] .On average, estimated CO_2 emissions from gasoline and diesel based on carbon content are as follows[121]:

- CO_2 Emissions from a litre of gasoline: 2.35 kg CO_2/litre
- CO_2 Emissions from a litre of diesel: 2.69 kg CO_2/litre

It is important to note that even though CO_2 emission values for diesel are higher than those for gasoline, these are generally offset by the higher fuel economy achieved by diesel vehicles[122].

[115] Airports Authority Trinidad and Tobago and Trinidad and Tobago Energy Commission. PIARCO International Airport: Master Planning and the Environment. Unpublished document provided by Sherwin Seyjagat, Duty Manager at the Airports Authority of Trinidad and Tobago

[116] PIARCO Air Services Limited, personal communication, October 3, 2016

[117] Swissport Trinidad and Tobago Ltd, personal communication, October 10, 2016.

[118] NVG America. Natural Gas Environmental Benefits. Retrieved from http://www.ngvamerica.org/natural-gas/environmental-benefits/

[119] EPA. Questions and Answers: Greenhouse Gas Emissions from a Typical Passenger Vehicle. Office of Transportation and Air Quality EPA-420-F-14-040a, May 2014. Retrieved from https://www.epa.gov/sites/production/files/2016-02/documents/420f14040a.pdf

[120] NGC, personal communication, February 2, 2016

[121] U.S. EPA. Questions and Answers: Greenhouse Gas Emissions from a Typical Passenger Vehicle. Office of Transportation and Air Quality EPA-420-F-14-040a, May 2014. Retrieved from https://www.epa.gov/sites/production/files/2016-02/documents/420f14040a.pdf

[122] U.S. EPA. Questions and Answers: Greenhouse Gas Emissions from a Typical Passenger Vehicle. Office of Transportation and Air Quality EPA-420-F-14-040a, May 2014. Retrieved from https://www.epa.gov/sites/production/files/2016-02/documents/420f14040a.pdf

Under those parameters, the following Table 11 shows potential CO_2 emissions savings from GSE at PIARCO International Airport if the entire fleet were converted to CNG:

Gasoline	PIARCO
Total No. of Vehicles	21
Total fuel consumption l/yr	31,003
CO_2 kg/l emissions	2.348
total CO_2 emissions kg/yr	72,785
CO_2 kg/l savings with CNG %	30
total CO_2 emissions savings kg/year	**21,835**
Diesel	**PIARCO**
Total No. of Vehicles	53
Total fuel consumption l/yr	722,256
CO_2 kg/l emissions	2.689
total CO_2 emissions kg/yr	1,942,344
CO_2 kg/l savings with CNG %	30
total CO_2 emissions savings kg/year	**582,703**
TOTAL CO_2 Emissions Savings kg/yr	**604,539**

TABLE 11
Estimated CO_2 emissions reductions from use of CNG on GSE

These calculations offer a rough estimate of potential CO_2 emissions reductions achievable with the use of CNG as a transport fuel. For accurate results, each type of vehicle needs to be tested on fuel consumption and tailpipe emissions individually. This scenario assumes that the use of CNG delivers greater or similar fuel efficiencies to Gasoline or Diesel for GSE, and thus similar GSE capabilities.

There are two potential locations for the installation of CNG stations to serve GSE at PIARCO International Airport[123]. In both cases, an active pipeline runs nearby facilitating access to natural gas supply. The following Figure 15 identifies these locations:

FIGURE 15
Potential sites for the location of CNG fuelling stations at PIARCO International Airport

The break-even point for a customary CNG service station is about 86,000 gasoline equivalent litres per day in sales, which equates to servicing between 200-300 vehicles per day[124]. There are only 74 GSE vehicles operating at PIARCO International Airport so these fuelling stations will need to serve both the common public and GSE to become economically viable. It takes about two years for the construction of one of these stations to complete so this is a medium term solution worth exploring to reduce GHG emissions from GSE.

In the short term, the option is to set-up two mobile CNG service stations with an estimated fuel capacity of 2250 gasoline equivalent litres per day each. These CNG stations are placed on a trailer that can be moved to different locations, with all safety and operation permits required by law. The NGC sells these mobile stations in Trinidad and Tobago. The client can opt to lease or purchase the station, and it can also chose to run it or hire the NGC or an alternate service provider to take over operations. The following Table 12 states estimated purchase costs of a mobile CNG station:

Variable	TT$
Capex	22,000,000
Infrastructure	200,000
Commission	150,000
Total	**2,350,000**

TABLE 12
Estimated Costs for a 2250 litres CNG Mobile Service Station. Source: NGC[124]

Capital expenditures (CAPEX) costs include CNG equipment (compressor, dispenser, and storage) and the needed infrastructure is the trailer where the mobile station is placed. Operating costs include all inputs and at least one employee as regulation requires the presence of trained personnel at all times during hours of operation.

GSE operators can take advantage of the following government incentives when retrofitting or purchasing vehicles powered by CNG:

a) Removal of Motor Vehicle Tax and Value Added Tax on imported vehicles (less than 2 years old) which are manufactured to use natural gas.
b) For Fleets – Capital uplift of 130 per cent for wear and tear allowance on the cost of converting a vehicle to use CNG

Savings in maintenance and fuel costs also act as incentives are for GSE operators to consider a switch from conventional fuel to CNG. As long as there is a high flow CNG fuel station on the north and south terminals of PIARCO International Airport, both Swissport and PAS expressed their willingness to update their fleets to CNG powered vehicles[125].

[123] Airports Authority of Trinidad and Tobago, personal communication, October 3, 2016
[124] NGC, personal communication, February 2, 2016
[125] PIARCO Air Services Limited, personal communication, October 3, 2016; Swissport Trinidad and Tobago Ltd, personal communication, October 10, 2016.

b) Biodiesel Processed from Used Cooking Oil

A renewable and more sustainable option to CNG to achieve greater GHG emissions reductions from GSE is the use of biodiesel produced from used cooking oil (UCO) on diesel vehicles.
In fact, in 2014, the University of West Indies (UWI) published a paper evaluating the production of biodiesel made from UCO to power buses transporting students along university campuses. The investigation involved the collection of UCO from nearby restaurants for consequent conversion into biodiesel[126].

Overall lab results were not very encouraging. Technology used for the conversion process was too basic and could not handle the high level of impurities present in the UCO provided form local restaurants. In addition, the study did not include an economic analysis, which is crucial to determine the feasibility of most projects. Nevertheless, results revealed the willingness of restaurants to participate and positively contribute to the recycling of UCO into alternative fuels.

Green Fuels, a technology company located in the United Kingdom, offers an advanced biodiesel processor, the FuelPod4, capable of handling UCO with high level of impurities like that one available from Trinidad and Tobago restaurants. TheFuelPod4 produces biodiesel at small scales, ideal to supply the GSE fleet at PIARCO International Airport with a reported annual diesel consumption estimated at 722,256 l/yr[127]. Table 13 below shows estimated CAPEX and OPEX costs for the FuelPod4 to supply approximately 7.6 per cent of total diesel annual consumption by GSE with biodiesel[128].

TABLE 13

Estimated costs for FuelPod 4 - Biodiesel for GSE.

Source: GreenFuels[128]

Green Fuels FuelPod4*		
Production capacity	litre/day	150
	litres/year	54,750
FuelPod 4 CAPEX**		$173,713.08
Income total (excl VAT)		$132,328.34
Production costs total		$73,452.24
Profit before tax and interests		$58,876.10
CO_2 Savings (2.7kg/litre displaced)		147,825

*Basic economic calculation for a typical year of operation
**Exchange rate TT$/£ = 8.354

The use of biodiesel processed from UCO on GSE at PIARCO International Airport will help reduce CO_2 emissions form the aviation sector but because the vehicle fleet is small, its incidence on overall environmental needs and international commitments (INDCs) will not offer significant benefits. Nevertheless, the pilot project does make economic sense with a net present value calculated at TT$379,045 over ten years as illustrated below on Table 14.

TABLE 14

Net Present Value FuelPod4

Source: GreenFuels[128]

NPV (discount rate at 6.75%)			
Year	Present Value	Year	Present Value
t=0	$ (162,729)	t=6	$ 51,525
t=1	$ 71,426	t=7	$ 48,267
t=2	$ 66,910	t=8	$ 45,215
t=3	$ 62,679	t=9	$ 42,356
t=4	$ 58,716	t=10	$ 39,678
t=5	$ 55,003	Total	**$ 379,045**

In the medium term, the biodiesel blend mix to power GSE could be augmented to 30 per cent. Though the research conducted by UWI revealed that available volumes of UCO are not sufficient to supply all diesel vehicles in the nation, enough could be collected to allow expanding the use of biodiesel on additional road vehicles like public buses or buses transporting students along university campuses. This initiative can become a public awareness campaign to inform the general public of the Nation's commitment to environmental protection and efforts to diversify the energy sector.

[126] Rachael R. Wyse-Mason, Denise M. Beckles. An investigation of restaurant waste oil characteristics for biodiesel production in Trinidad and Tobago. University of the West Indies, St. Augustine, Trinidad and Tobago. Retrieved from http://www.sciencedirect.com/science/article/pii/S0973082612000361

[127] It was not possible to obtain total number of GSE vehicles operated by Swissport and the Fire Services as well as total fuel consumption. The full GSE vehicle fleet at PIARCO International Airport was estimated from information sent by Julian Chance (ANRRIA Airports Authority of Trinidad and Tobago) though it was not segregated by entity. Fuel consumption for Swissport's GSE fleet was extrapolated from data provided by PAS on their fuel consumption on both gasoline and diesel powered vehicles for 2017. PAS did provide accurate data on their GSE vehicle fleet size, vehicle fuel type, and total estimated fuel consumption on a monthly basis for year 2017

[128] Green Fuels, personal interview, November 19, 2016

7. POLICY AND REGULATORY FRAMEWORK

Policy promotes nascent industries by bridging the gap to achieve price parity with competing businesses that have already achieved economies of scale. Effective national policy is carefully drafted to ensure that unintended negative effects to other sectors are counteracted or controlled. The emerging industry for SAFs is particularly different in that it not only needs strong national policy to grow, but also a harmonization among international participants to compete jointly with fossil fuels. As the GORTT advances to fulfil its commitments under declared INDCs, the use of SAFs should be part of a nationwide strategy for the use biofuels to reduce GHGs in all transportation sectors including aviation, marine, and land.

7.1 WORLD OVERVIEW ON SUSTAINABLE AVIATION FUELS

Several countries around the world have made important progress on policy development to promote the use of SAFs. The European Union, with its Biofuels Flightpath project, has set a target of two million tonnes per year of aviation biofuels in Europe in 2020, which is about 3-4 per cent of total jet fuel use in Europe. Aviation Initiative for Renewable Energy in Germany has set a target of 10 per cent of alternative aviation fuel for 2025. Indonesia has introduced a SAF mandate of 2 per cent commencing in 2016, rising to 5 per cent by 2025.

In the U.S., the EPA's RFS framework provides producer credits in the form RINs of that allow renewable jet to be competitively priced with conventional jet fuel[129]. This scheme has allowed Fulcrum Bioenergy to offer BTL-SAFs processed from MSW at price parity with conventional jet fuel. In 2014, Fulcrum signed a forward purchase contract with Cathay Pacific for 375 million gallons of biofuel over ten years[130].

Brazil is considering the inclusion of the use of SAFs as part of the Nation's laws legislating the use of biofuels in the transport sector. The proposal includes different forms of regulation comprising the entire chain of production[131].

None of the above policies are perfect. The U.S. EPA had to confront serious accusations of loopholes in the RFS RIN scheme involving millions of dollars of taxpayers' money[132]. The European Union's Biofuel Flightpath project was in the news recently under accusation from the European biofuels industry for supporting oil[133]. Nevertheless, existing mandates are paving the way for growth in the global industry for SAFs.

Unlike the U.S. and the European Union, Canada chose to reduce risks and instead of developing their own policy from scratch, they adapted California's Low Carbon Fuel Standard LCFS into their own National Clean Fuel Standard (yet to pass enactment) tailored to their needs, adopting those measures proven as successful and avoiding mistakes.

7.2 POLICIES IN TRINIDAD AND TOBAGO FOR SUSTAINABLE AVIATION FUELS

Considering Trinidad and Tobago's limited experience with biofuels, following Canada's approach of adopting and adapting foreign legislation to develop a National Clean Fuel Standard might prove as a suitable strategy when designing legislation to control GHG emissions. It is essential for the standard to address a broad suite of fuels, including liquid, gaseous and solid fuels, and that it goes beyond transportation fuels to include those used in industry, homes and buildings so that costs and benefits from compliance are incurred equitably by all stakeholders.

A clean fuel standard will stimulate direct investments in a variety of lower carbon fuel options and is particularly effective because all compliance costs are directed back into lower carbon solutions[134]. Efficient policy to reduce GHG emissions at a national level would be a flexible, performance-based approach on a lifecycle carbon intensity basis that includes a market-based mechanism, such as a crediting and trading system.

For the aviation sector in particular, it would be of interest for Trinidad and Tobago to participate in ICAO's CORSIA. This will allow Caribbean Airlines to fairly compete with international carriers in reducing CO_2 emissions. Trinidad and Tobago's active role in CORSIA will also assure that the interests and needs of small island states are addressed when setting global requirements of emissions reduction from international aviation.

Control of emission from GSE in Trinidad and Tobago airports would be regulated under requirements for the overall land transport industry on a National Clean Fuel Standard. Nevertheless, to warrant success on the use of biodiesel made from UCO as transitional SAFs for GSE, additional incentives might be needed for the active and long term involvement of UCO suppliers. A campaign with some form of recognition similar to a unique sticker, plaque, or published listing to distinguish those food vendors that cooperate by donating their UCO could serve to expand the network to allow for higher blending percentages in the fuel mix for GSE.

For Trinidad and Tobago airports, the promotion of direct investment in lower carbon fuel options through a National Clean Fuel Standard would mean increased investment in solar and wind power generation over most biofuels to power energy needs.

8. KEY FINDINGS & CONCLUSIONS

After careful evaluation of data provided by major stakeholders as well as literary sources and secondary data collected, the following list details key findings that can help rapidly reduce GHG emissions from Ground Support Equipment (GSE) and define Trinidad and Tobago's suitability for the deployment of Sustainable Aviation Fuels (SAFs):

a) The lack of suitability in quantity and quality of locally sourced sustainable feedstock makes the current deployment of SAFs in Trinidad and Tobago economically unviable.

b) Additional, feedstocks potentially available in Trinidad and Tobago like petrochemical waste gases, sugar cane and bagasse, and algae have proven unsuitable in quality, quantity, or financially for conversion into SAFs.

c) Existing wealth and broad expertise in fuel management from an established petrochemical industry gives Trinidad and Tobago the right tools to play a primary role in the supply of Sustainable Aviation Fuels in the Caribbean region once markets become competitive and prices are set by market forces.

d) Current developments at Pointe-A-Pierre on the production of advanced GTL-FT processing technology can offer a future comparative advantage to Trinidad and Tobago for the rapid deployment of Sustainable Aviation Fuels.

e) One possible option for Trinidad and Tobago could be the future set-up of a BTL plant using FT technology for the production of BTL-SAF, a SAF sourced from renewable resources like MSW and agricultural residues.

f) Any considerations to produce SAFs using current proven technology will require foreign imports to complement locally sourced renewable feedstock (MSW, agricultural residues, etc.)

g) The future development of small scale BTL processing technology could make viable the deployment of SAFs for local and regional consumption in Trinidad and Tobago using locally sourced waste feedstocks (MSW) given the premise that landfills are equipped with engineering technology capable of capturing and processing LFG.

h) Trinidad and Tobago can rapidly begin to lower CO_2 emissions from the aviation sector by targeting GSE.

i) The installation of a solar farm at PIARCO International Airport to power plug-in electric vehicles offers the most sustainable option to reduce CO_2 emissions and other pollutants from GSE fleets.

j) Though not considered renewable fuels, the following two measures could serve as effective transitional actions to help reduce CO_2 emissions from GSE:

i. Replacement or retrofit to CNG of gasoline powered GSE vehicles at PIARCO International Airport resulting in CO_2 emissions reductions of approximately 21,835 kg/yr.

ii. Use of a 30 per cent blend mix of biodiesel processed from UCO to power diesel powered GSE vehicles resulting in CO_2 emissions reductions of approximately 739,563 kg/yr.

[129] Bryan Sherbacow. Paramount GreenJet Refinery. AltAir Fuels. Retrieved from https://www.smgov.net/uploadedFiles/Departments/Airport/Sustainability/20150126_AltAir_Presentation.pdf

[130] Dan Lee. Hong Kong's Cathay Pacific Seeks 80pc Emissions Reductions on some Long Flights with Big Switch to Biofuels. Retrieved from http://app.scmp.com/scmp/mobile/index.html#/article/2066549/desktop

[131] Gol Airlines, personal communication, December 13, 2016.

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9. RECOMMENDATIONS

The following is a list of recommendations for the short, medium, and long terms worth considering as the Government of the Republic of Trinidad and Tobago (GORTT) takes action to achieve the Nation's commitment on sustainable development. Suggestions extend beyond the aviation sector to ensure that efforts affect all stakeholders similarly, enjoying benefits and confronting costs collectively. Regardless of the term, it is crucial for Trinidad and Tobago to maintain strong government commitment with global efforts to reduce GHG emissions from the aviation sector and ensure that the Nation remains influential and plays and active role in the development of markets for SAFs.

9.1 SHORT TERM (1-5 YEARS)

a) Develop a nationwide strategy for carbon pricing and GHG emissions, and the use of SAF, and biofuels for use in marine, and land transport.

b) Reinforce the government's support to ensure the efficient development of the GTL-FT industry to gain a comparative advantage in the future production and commercialization of renewable BTL-SAFs.

c) Evaluate the feasibility, and if viable install a solar farm at PIARCO International Airport to supply renewable energy for airport operations including powering Electric Vehicles (EVs) for GSE.

d) While evaluations are on-going to incorporate EVs powered by solar panels at PIARCO International Airport, Trinidad and Tobago can rapidly begin to reduce GHG from GSE through the following transitional measures:

   i. The provision of 7.6 per cent biodiesel processed from used cooking oil to fuel diesel powered GSE.

   ii. The installation of two mobile high-flow fuelling CNG stations in the north and south terminals to power GSE fitted to run on CNG.

9.2 MEDIUM TERM (5-10 YEARS)

a) Revise and modify existing policy on the handling and disposal of waste from residential, industrial, and commercial sectors to ensure selective disposal of the organic portion:

   i) Develop and launch capacity building workshops and training sessions on recycling and organic waste separation for the general public, and academic and public institutions

   ii) Explore the idea of updating the nation's waste sites to engineered advanced landfills to allow for the capture of LFG and use of the CH4 portion as an affordable local source of renewable feedstock for BTL-SAF production.

b) Investigate and if feasible, increase to 30 per cent the blend mix of biodiesel produced from UCO for GSE.

9.3 LONG TERM (10+ YEARS)

a) Evaluate supplementing volumes of existing waste biomass, including MSW, with imports from, and cooperation with neighbouring nations

b) Develop nationwide specific routes for the collection of organic residential and industrial waste as well as agricultural waste separately from MSW collection routes

c) Conduct a feasibility study, including economic analysis, and consequent pilot project for the deployment of BTL-SAFs processed from imported and local renewable waste biomass.

d) Enact policy to support the use of EVs for private and public vehicle owners.

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13. ANNEX I
SUMMARY OF THE RECOMMENDED ROADMAP

TRINIDAD AND TOBAGO 10-years Roadmap and Action Plan - Sustainable Aviation Fuels (SAFs)

VISION

Create a new Economic sector to reduce GHG emissions from the aviation industry, generate new regional, high-value and knowledge-intensive jobs, and Foster innovation and development in Trinidad and Tobago

STRENGTH

Government committed to reduce CO_2 emissions from transport	Highly skilled workforce on liquid fuel production and management	World-class expertise in fuel refining and processing technology	Broad experience in the commercialization of liquid fuels	Strategically located-market access to the Caribbean & the Americas

CHALLENGES

Limited feedstock options	GDP highly dependent on fossil fuels	Weak ties between government, industry and academics	Local policy to commercialize SAFs increases investment risk

SHORT TERM (1-5 YEARS)
Provide direct support to specific industry developments

ACTION

- Develop a nationwide strategy for carbon pricing and GHG emission, and the use of biofuels for aviation, marine, and land transport.
- Reinforce government's support to ensure the efficient development of the GTL-FT industry to gain a comparative advantage in future markets for BTL-SAFs.
- Evaluate the feasibility, and if viable install a solar farm at PIARCO International Airport to supply renewable energy for airport operations including powering EVs for GSE.
- While evaluations are on-going to incorporate EVs powered by solar panels at PIARCO International Airport, TT can rapidly begin to reduce GHG from GSE through the following transitional measures:
    - i. The provision of 7.6 per cent biodiesel processed from used cooking oil to fuel diesel-powered GSE.
    - ii. The installation of two mobile high-flow fueling CNG stations in the north and south terminals to power GSE flitted to run on CNG.

MEDIUM TERM (5-10 YEARS)
Plan for the deployment and promote SAFs

ACTION

- Revise and modify existing policy on the handling and disposal of waste from residential, industrial, and commercial sectors to ensure selective disposal of the organic portion:
    - i. Develop and launch capacity building workshops on recycling and organic waste separation for the general public, and academic and public institutions.
    - ii. Explore the idea of updating the nation's waste sites to engineered advances landfills to allow for the capture of LFG and use of the CH_4 portion as an affordable local source of renewable feedstock for BTL-SAFs production.
- Investigate and if feasible, increase to 30 per cent the blend mix of biodiesel produced from UCO for GSE.

LONG TERM (10+ YEARS)
Support R&D on large scale production of SAFs

ACTION

- Evaluate supplementing volumes of existing waste biomass, including MSW, with imports from neighboring nations.
- Develop nationwide specific routes for the collection of organic residential and industrial waste as well as agricultural waste separately from MSW collection routes.
- Conduct a feasibility study, including economic analysis, and consequent pilot project for the deployment of BTL-SAFs processed from imported and local renewable waste biomass.
- Enact policy to support the use of EVs for private and public vehicles owners.

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