Bio-Kerosene GHG Emission Cocktail: Fast Forward Into Clean Air – Against all Odds

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High oil prices, limited resources, and environmental concerns are compelling airlines to turn to renewable sources of energy that will satisfy energy demands with minimal environmental impact. The good news is the aviation sector has set aggressive targets to reduce the air travel environmental footprint. However, the world's airlines face a painful challenge; of all the main energy sources, aviation fuel is going to be the most difficult to replace with low carbon equivalents. Biofuels provide a viable alternative to conventional fuel and enable airlines to reduce their environmental impact. Over the last three years biofuels for aviation have matured from novelty towards commercialization. JATRO and BioJet have been pioneering ways to develop and commercialize biofuels from plants such as jatropha and camelina that do not compete with food crops for land or water. These sustainable fuels, which have a smaller lifecycle carbon footprint than petroleum-based products, have proven that they can efficiently power commercial flights.

Jatropha bio-kerosene Overview of positive fuel properties and impacts	
Technology	• Has demonstrated full airworthiness in daily flight operations
	• Has been proven reliable and technically safe to use on scheduled passenger flights
	• Certified for use in commercial aviation via ASTM D7566
	• Improves engine performance (because of higher energy density)
Economy	• Reduces overall fuel consumption(for the same thrust)
	• Performs as well as or better than than JP-8 or Jet-A1 fuel
Ecology	• Burns cleaner (less & smaller particle emissions) than conventional kerosene
	• Does not require aircraft or engine modification
	• Cost-competitive with fossil fuels
Biosphere	• Contributes to Climate Change and reduces CO_2-emissions up to 85% relative to fossil based aviation fuels
	• Does not compete with food crops for land or water
	• Meets all sustainability criteria (social, economic, environmental)
Society	• Preserves biodiversity and sustains eco-balance
	• Prevents illegal logging and regenerates degraded soils
	• Stimulates rural development through employment generation
	• Creates jobs in the feedstock supply chain
	• Supports sustainable livelihoods and alleviates poverty

- And yet, the critics do not want to fall silent!
  This is at least irritating, if not irresponsible.

I. Aviation: The Usual Suspect

Fleets of shiny aluminium fuselages are obviously more attractive to focus on than other far bigger environmental offenders. Given its symbolic and visible prominence high in the sky, the aviation industry keeps being unfairly attacked over its environmental record and singled out despite its achievements and other industries being more egregious polluters.

While as of June 2012 more than 30 airlines have been successfully replacing petroleum based kerosene with biofuels, it seems like every newly announced effort to reduce aviation’s overall impact on the environment instantly attracts environmentalists' criticism of aviation's emissions record anew.

The *following analysis* tries to draw a fair account of the airline industry’s overall environmental impact in relation to other industries, in particular the shipping sector.

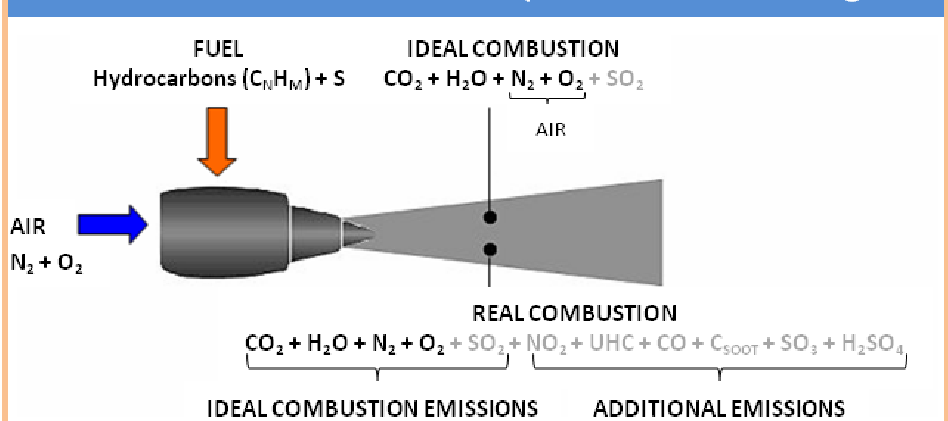
Aviation contributes to climate change and air pollution by the burning of fossil fuel. When fossil fuels are burnt, they are essentially releasing carbon that was sequestered in the earth for millions of years. Meanwhile, because biofuel feedstock sources absorb carbon dioxide during the growth process, when they are burned the result could be a zero net increase in carbon dioxide emissions. They provide a closed-loop system, by in effect recycling carbon in a short time frame.

Given its proven properties, hydro-treated jatropha and camelina derived bio-kerosene allows the replacement of traditional jet fuel and is a first leap towards the sustainable future of aviation. Jatropha and camelina are definitely no wonder plants that offer a cure to all known climate change challenges. As a consequence, plant based jet fuel does neither allow travelling at warp speed nor is the combustion process in aircraft engines completely emission free.

Far from it, even drop-in' capable fuels from jatropha nuts and other renewable raw materials which possess properties better than petroleum based Jet A-1 kerosene will continue to pollute the air and atmosphere – **just at reduced levels and in a less harmful way**. In other words, as long as aircraft are powered by gas turbine engines that consume fuel, sustainable jatropha and camelina based bio-kerosene is simply the best option available for the time being.

II. The Combustion Process

Aircraft generate the same types of emissions as automobiles. Aircraft jet engines are basically gas turbines, spinning devices that use the action of a fluid to produce work. The name "gas turbine" is somewhat misleading, because to many it implies a turbine engine that uses gas as its fuel. Actually a gas turbine has a compressor to draw in and compress gas (most usually air); a combustor (or burner) to add fuel to heat the compressed air; and a turbine to extract power from the hot air flow accelerated into the atmosphere through an exhaust nozzle to provide thrust or propulsion power. The combustion of a fuel-air mixture in an aircraft engine is a complex, unsteady, turbulent process governed by a set of non-linear



Schematic showing the emissions produced in the ideal and real combustion processes for aero engines partial differential equations involving hundreds of intermediate reactions that produce a number of additional emissions to ideal combustion.

III. Aircraft Emission Cocktail

Emissions from Combustion Processes (Overview)	
CO_2	Carbon dioxide is the product of complete combustion of hydrocarbon fuels like gasoline, jet fuel, and diesel. Carbon in fuel combines with oxygen in the air to produce CO2.
H_2O	Water vapor is the other product of complete combustion as hydrogen in the fuel combines with oxygen in the air to produce H2O.
NOx	Increase GHG ozone – warming effect. Nitrogen oxides are produced when air passes through high temperature/high pressure combustion and nitrogen and oxygen present in the air combine to form NOx, a key constituent of ozone. The quantity of emissions of other transport modes far exceeds aviation's NOx contribution.
SOx	A general term that refers to various mono-sulfur oxides, which are produced by the reaction of sulfur in coal and petroleum and oxygen in the air during combustion.
HC	Hydrocarbons are emitted due to incomplete fuel combustion. They are also referred to as volatile organic compounds (VOCs). Many VOCs are also hazardous air pollutants.
CO	Carbon monoxide is formed due to the incomplete combustion of the carbon in the fuel

Emissions from aircraft engines in an ideal combustion process that impact local air quality are those directly dependant on the chemical composition of the fuel. As shown in the schematic breakdown, these are carbon dioxide (CO_2), water vapour (H_2O) and sulphur dioxide (SO_2). The quantity of these emissions depends directly on the amount of fuel burnt in the engine and in the case of SO_2, on the sulphur content of the fuel.

The additional emissions that are produced during an aircraft engine combustion are oxides of nitrogen (NO and NO_2 which together are called NO_x), un-burnt or partially combusted hydrocarbons (UHC), carbon monoxide (CO), soot, sulphur trioxide (SO_3) and sulphuric acid (H_2SO_4), which together with sulphur dioxide (SO_2) are called SO_x. The emission of SOx has different consequences for the atmosphere: SO2 is oxidised to SO3 and eventually forms sulphuric acid, which contributes to acid rain and provides cloud conden-sation nuclei by formation of secondary particles, thereby increasing the albedo, i.e. the percentage of solar energy reflected back by the surface.

The quantity of these emissions depends on both the amount of fuel burnt and on the conditions in the combustor (such as temperature and pressure, combustion duration at different air/fuel ratios, etc). About 10 percent of aircraft emissions of all types, except hydro-carbons and CO, are produced during airport ground level operations and during landing and takeoff. The bulk of aircraft emissions (90 percent) occur at higher altitudes.

Crude Jatropha Oil has less than 5 percent of the sulfur content of alternative biofuels, resulting in significant reductions in sulfur dioxide emissions – a major contributor to acid rain-related environmental impacts -. Even better, hydro-treated green aviation fuel does not contain any traceable amount of impurities that could affect the performance of the fuel. In particular, it is virtually sulfur-free.

IV. Carbon Dioxide (CO_2)

Of the three main aviation emissions contributing to climate change, CO_2 is believed to be the most significant in the long term (i.e. when considering effects over a number of years). CO_2 is a long-lived greenhouse gas (50 - 200 years) so gets mixed throughout the atmosphere and has the same effect whether it is emitted by an aircraft engine at altitude or by another source at ground level. Its behaviour in the atmosphere is simple and relatively well understood; it causes direct positive radiative forcing (warming) of the troposphere. Aircraft engine emissions are roughly composed of about 70 percent CO_2, a little less than 30 percent H_2O, and less than 1 percent each of NO_x, CO, SO_x, particulates, and other trace components.

Transport-sector CO_2 emissions represent 23% (globally) of overall CO_2 emissions from fossil fuel combustion. The sector accounts for approximately 15% of overall greenhouse gas emissions. Emissions from global aviation and international shipping account for about 3% each of total CO_2 emissions.

V. We have A Winner

Bio jet fuel created from jatropha and camelina seeds has demonstrated in numerous flight operations that hydrotreated renewable jet fuel reduces carbon emissions (CO_2) by up to 85% compared to conventional petroleum jet fuel. The decrease in CO_2 emission for Jatropha based bio-kerosene is attributed to the high cetane number and the presence of oxygen in the molecular structure of the jatropha fuel. It should be fair to acknowledge that the positive effect on CO_2 emission reduction alone translates into significant Green House Gas (GHG) savings. All other things being equal, the sheer magnitude of this GHG reduction alone more than justifies the gradual transition towards a green fuel blend in the aviation industry. Add to this the basically sulfur free fuel properties – and jatropha based bio-kerosene demonstrates a significantly better environmental performance than fossil fuel.

Nevertheless, the critics persist and still refuse recognition. Just like her unjust stepmother tries to prevent Cinderella from attending the prince's festival, biofuel opponents now zero in on the Non-CO_2 effects of aircraft emissions like NO_x which contributes to the formation of fine particles and the formation of ground-level ozone. Fine particles and ozone are even associated with thousands of premature deaths and illnesses each year.

VI. Is There A Dark Side Of Biofuels?

Findings from a recent study by the Massachusetts Institute of Technology (MIT) estimate that around 8,000 premature deaths per year globally can be attributed to the effects of

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oxides of nitrogen and sulphur (NO_x and SO_x) emissions from aircraft flying at cruise altitudes of around 35,000 feet. Aircraft emit nitrogen oxides (NO_x) and sulphur oxides (SO_x), which react with gases already existing in the atmosphere to form the harmful fine particulate matter (PM), sulphate and nitrate aerosols. Including the effects of landing and takeoff emissions another 2,000 premature deaths are attributed to aviation-related PM emissions up to an altitude of 3,000 feet.

At first sight and out of context these findings per se sound shocking. However, it makes sense to keep things in perspective and explore just a little further.

VII. Separating Facts From Polemics

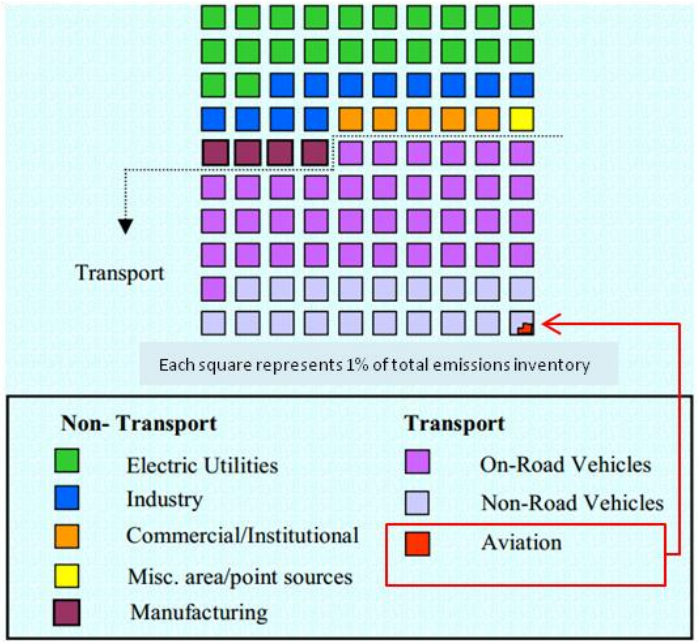
Most of the NO_x formed in the combustion process is due to the nitrogen and oxygen from the air combining at high temperatures. Its formation is a function of temperature, pressure and time at high temperatures. Accordingly, NO_x emissions vary significantly across the flight cycle, with the highest levels generated at take-off when the air entering the combustor has the highest pressure and temperature, and the peak combustion temperatures are highest. As a result, NO_x are for the most part dependant on aircraft engine technology and flight pattern instead of fuel properties. Thus, NO_x emissions can primarily be reduced through improvements in combustor and engine technology as well as airframe aerodynamics and modified takeoff and landing procedures.

As it turns out, the negative side effects of NO_x emissions are by and large unrelated to the underlying fuel properties. However, brought forward in a biofuel related context, critics suggest that green aviation fuels are bad because they don't reduce lethal NO_x emissions. With no evident causal or scientific link, it becomes obvious that this type of criticism is not really adressed against biofuels but against commercial air travel in general. As a consequence, the surface debate about biofuels is really about aviation. Critics feel encouraged to take a free ride on the availability of a global audience. Media attention on biofuels in the aviation sector just serves as the Trojan Horse or conduit to voice criticism not directed gainst biofuels per se but rather against airlines, air travel and flying as a non-environmentally conscious mode of transportation.

VIII. Putting Things Into Perspective

Further arguments to qualify (minimize) the impact of biofuels on potentially deadly NO_x emissions are illustrated by applying a more holistic view. Since essentially all NO_x come from combustion processes, it goes without saying that electric utilities, industry, and transportation are significant emitters. No surprise, they make up the largest share of the total inventory.

In addition, total NO_x emissions from on-road transportation dwarf emissions from all other transportation modes combined. While all transportation modes together constitute more than 55% of total NO_x emissions, aviation in comparison contributes less than 1% of air quality-related premature mortalities from all sources (*see illustration below*).



Even in cities with the greatest concentration of aviation activity and the largest national airports, total airport contribution (including aircraft, ground support equipment, and all other vehicles operating around the airport) contribute only a small percentage of NO_x emissions to regional inventories. In the case of New York, total airport contribution (incl. JFK, LGA, EWR) to the respective area NO_x inventory is 4.0% and related total aircraft contri-bution to non-road NO_x inventory is 13.8%.

The same situation applies for Hong Kong. Within Hong Kong, the main contributors of nitrogen oxides and particulate matter are electricity generation and road transport, which together account for about three-quarters of these pollutants. NO_x and particulate emissions from aircraft during landing and take-off (LTO) cycles (which include all activities near the airport that take place below the altitude of 3000 feet) account for 4% and less than 1% of the Hong Kong totals respectively.

IX. Shipping Emissions – Way Behind

In comparison to the groundbreaking achievements being introduced and implemented in the aviation sector with the advent of sustainable biofuels, the deadly impact of ship engine exhaust emissions on terrestrial air quality remains largely unnoticed. Just 20 of the world's biggest ships may now emit as much pollution as the entire world's 800 million cars. However, shipping emissions don’t seem to attract the kind of critical attention, the aviation sector is facing.

In comparison to aircraft, ships generally use low quality fuel to reduce costs. This low quality fuel tends to have high sulphur content. Low-grade ship bunker fuel (or fuel oil) has up to 2,000 times the sulphur content of diesel fuel used in US and European automobiles. As a consequence, SO_2 emissions are high. Emissions of oxides of sulphur (SOx) from shipping represent about 60% of global transport SOx emissions. Similarly, NO_x emissions from international ship traffic are significantly higher because most marine engines operate at high temperatures and pressures without effective reduction technologies. Emissions of oxides of nitrogen (NOx) from shipping represent about 15% of global anthropogenic NOx emissions and around 40% of global NOx emissions from transport of freight. Within 10-15 years, ships in the seas surrounding Europe are expected to emit more NOx than all land-based sources in EU27 combined.

X. Killing Particles

Pollution from the world's 17,000 cargo ships, 9000 bulk carriers, 5000 container ships and 13,500 Tankers leads to more than 60,000 deaths a year.

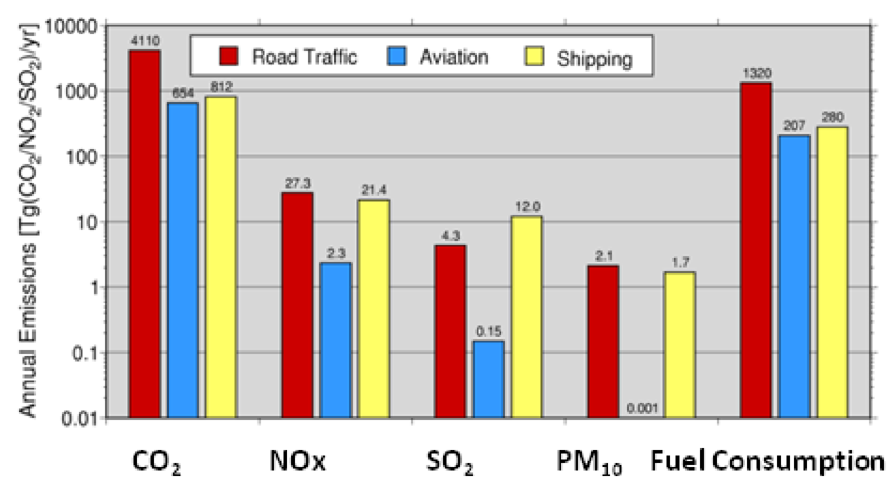
Particulate matter (PM) from engine exhausts, especially the finer particles, can lodge in the lungs and move into the bloodstream, leading to cardiovascular and pulmonary disease. Scientists predict accelerated mortality from ship emissions. Scientific results indicate that particulate emissions from ships are responsible for approximately 64,000 cardiopulmonary and lung cancer deaths annually, mostly near coastlines in Europe, East Asia and South Asia. Around 70% of ship emissions occur within 400km of land.

Recent findings suggest that the fatality rate from shipping related PM emissions will increase by 30% in 2012, i.e. to 84,000 premature mortalities. In addition, this mortality estimate does not account for additional health impacts such as respiratory illnesses like bronchitis, asthma, and pneumonia. These health impacts are particularly concentrated in areas of Southeast Asia and Europe.

Today, estimated particulate matter and ozone-related human health impacts associated with ship emissions in the U.S. and Canada count up to 21.000 premature deaths annually and 8.9 million cases with acute respiratory symptoms. The comparative numbers for European coastal waters are even more deadly.

If no additional abatement measures are taken, by 2020 the emissions from shipping around Europe are expected to equal or even surpass the total from all land-based sources in the 27 EU member states combined. As a consequence, the number of annual deaths from ozone and PM exposure in Europe is likely to stay high.

According to the Danish Centre for Energy, Environment and Health (CEEH), emissions from international ship traffic are already responsible for external costs related to impacts on human health of 58 billion Euros/year, corresponding to 7% of the total health costs in Europe in 2000, and increasing to billion 64 Euros/year in 2020, corresponding to 12% of the total health costs. 75% of the urban population of southern Europe and 40% of that in Northern Europe live in cities where the ozone level exceeds the EU air quality standard. Exposure to high levels of ozone and particulate matter (PM) results in 370,000 cases of premature death annually.



Transport related annual emissions of CO_2, NOx, SO_2, and PM_{10} and fuel consumption in Tg (1 TG = 1 x 10^{12}g = MT) est. for the year 2000

The most straightforward method of reducing SOx emissions is to reduce fuel sulphur content. There is a limit to how low the sulphur content of heavy fuel oil can be reduced. Heavy fuel oil is largely composed of the thick residue from the crude oil refining process, to which lighter components have been added to bring it to a useable consistency. It is black in colour. The majority of shipping runs on heavy fuel oil. IMO Marpol Annex VI will allow global fuel sulphur content of 3.5% until 2020. By comparison, the diesel fuel used for road transport (ULSD) contains only 0.0010% sulphur by mass. Higher quality diesel fuels which are known as Marine Diesel Oil (MDO) are available, but they come at a greater cost.

Based on ship emission inventory reductions due to switching from 2.7% sulphur residual fuel to 0.1% sulphur distillate fuel and an overall fleet NOx reduction of 23% until 2020 in the US and Canada alone it is expected that as many as 14,000 lives can be saved and nearly five million people will experience relief from acute respiratory symptoms each year, translating into overall monetized benefits of USD 47-110 billion.

XI. Conclusion – The Case for Sustainable Plant Oils

The above references are meant to shed some light on the constant danger of misperceptions and misinterpretations. The presentation of select details can easily result in a distorted view. As a consequence, an uneducated public may fall victim to the first best surface argument brought forward by interest or lobby groups. This is particularly true for a heated biofuel debate where the good, the bad and the ugly are not always easy to distinguish at first sight. This classification applies to the choice of particular feedstock as well as to the key players in the plantation and biofuel industry. For many activists the intentional lack of differentiation and unwillingness to look beneath the surface often serves the purpose of a quick and dirty specious argument, speculating on the audience's inability to validate and verify ad hoc any particular claim.

This comment is an appeal to put things into perspective. At times this may require an extra effort from the addressee, especially if the initial arguments offered are tempting to fall for as they usually offer the path of least resistance. Recognizing the merits of a good and pragmatic solution, i.e. the conversion of jatropha and camelina crude oil into high grade bio-kerosene, doesn't stop the search for continuous improvement on the related feedstock and technology levels.

In the end and against all odds, even Cinderella achieved unexpected recognition and success after a period of neglect.

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