Future Sustainable Practice for Formula 1 Logistics

Hope Ross

201985232

Supervisor: Mr Cameron Johnston

Department of Mechanical and Aerospace Engineering

University of Strathclyde, Glasgow

A thesis submitted in partial fulfilment for the requirement of the degree

Master of Science

Sustainable Engineering: Renewable Energy Systems and the Environment

2020

Abstract

The following project investigates sustainable practice within Formula 1 (F1) logistics to facilitate the sports target of net-zero carbon emissions by 2030. Logistics is the largest carbon emitting sector in F1, responsible for 45% of the overall carbon footprint therefore change is critical if the sport aims to attain its goal. Initially CO_2e (CO_2 equivalent) emission were calculated individually for road, sea and air freight of current F1 logistics, with the aim to highlight the potential CO_2e reductions through an alternative Grand Prix seasonal calendar. The alternative calendar showcased an efficient schedule with a progressive route accounting for climate conditions; ensuring optimum weather conditions to secure race execution. This alternative calendar showcased a 44% CO_2e saving compared to original 2019 Grand Prix calendar with more road transportation promoted and fewer sea/air travel required.

Finally the project focused of the adoption of biofuel in all three methods of freight transport. Road freight transporters investigated the use of Liquefied Natural Gas (LNG) alongside bioethanol. Sea freight transporters examined adopting methanol or ammonia based fuels and finally air freight explored the use of jatropha synthetic paraffinic kerosene (SPK) and bioethanol. Research projects then confirm or deny whether these biofuel are achievable to implement in the near future.

For F1 to majorly reduce their logistic CO_2e emissions within a short period of time, the alternative calendar would be their best option, with little adaptations or modifications required of the freight transporters.

Acknowledgements

Whilst completing this project I have been supported by many different people but I would like to thank my supervisor Cameron Johnston, for his advice and support. The Scottish Power foundation for their scholarship opportunity and finally, my family, friends and fellow colleagues for their encouragement throughout my years at university.

Contents

List of Figures

List of Tables

Chapter 1

Introduction

Established in the 1950's the first Grand Prix world championship series was administered, connecting national races undertaken in Monaco, United Kingdom, United States, Belgium, France, Italy and Switzerland. The motorsport in those days included a handful of teams alongside engineers that design, construct and race the cars, all for the title of world champion [1] Today the sport has over 500 million viewers worldwide [2] with a total of ten teams competing in twenty one races. Each Grand Prix is a three day event with testing and qualifying conducted on the first two days and the race on the third. All F1 teams enter two cars into the event with points awarded at the end of each race, the team with the most points are awarded champion at the end of the year. Winning secures additional sponsorship for the team, boosting financial assets to develop the car and opens up further employment opportunities for engineers and more desirable drivers. To ensure an exciting season of competitive balance the Federation Internationale de l'Automobile (FIA), the controlling organization of the F1 motorsport series, implements and monitors regulation changes which heightens the uncertainty of a team's performance as engineers must experiment with car design and shift race strategy. The uncertainty regarding race results attracts spectators to the sport, and therefore consequently attracts sponsors. [3]

Over recent years with the imminent effects of climate change, the sport has been under attack for its lack of interest or attempt in reducing their anthropogenic emissions each year.

In November 2019 the new owners, Liberty Media, issued its ambitious sustainability plan to attain a net-zero carbon footprint by 2030. The plan sets to encompass the F1 cars on-track activity alongside off track operations required to run the events. Initiatives will provide ultra-efficient travel and logistics alongside 100% renewable energy schemes to power the offices, factories and facilities incorporated within F1. Any sector with unavoidable carbon emissions will be offset.

Speaking about the future prospects of the motorsport, Chase Carey, Chairmen and CEO of F1 says:

"In launching F1's first-ever sustainability strategy, we recognise the critical role that all organisations must play in tackling this global issue. By leveraging the immense talent, passion and drive for innovation held by all members of the F1 community, we hope to make a significant positive impact on the environment and communities in which we operate. The actions we are putting in place from today will reduce our carbon footprint and ensure we are net zero carbon by 2030." [4]

The strategic plan aims to tackle F1 emission mitigation in two stages; firstly the motorsport plans to be sustainable by 2025 and after this the second stage is to produce net-zero emissions by 2030. Both stages prove ambitious for a sport which has to transport ten teams including a substantial volume of equipment associated to twenty one seasonal races. The plan however, does not include emissions generated by fans as this is outwith the organisations control, instead they will promote alternative forms of travel to hopefully influence spectators but will not include the fans travel arrangements in their analysis and outcomes. [5] Overall the governing body FIA intend to maintain the high level of competition which holds the interest of the large global audience. [3]

1.1 Aim and Objectives

Aim

This project aims to evaluate the future logistics of F1 becoming sustainable by 2025 and proceeding net-zero carbon emitting by 2030. Following their projected criteria and strategy outline, this thesis will analysis potential solutions and their contribution to the strategic plan, finally concluding if F1 are able to achieve what they have set out.

Objective 1: Investigate F1's current CO_2e emissions and define the greatest emitting sector (logistics). Next develop a spreadsheet to calculate the CO_2e emission breakdown within this sector (i.e. road, sea and air emissions). The specific distance travelled by each mode of transport, alongside weight (kg) of CO_2e emitted per journey, will be illustrated in a Microsoft Excel spreadsheet.

Objective 2: Create an alternative Grand Prix seasonal calendar and calculate the new logistic CO_2e emissions produced. The new calendar (based on the 2019 calendar) will ensure optimum climate conditions are experienced at each race weekend. Then original logistic emissions will be compared to the new calendar emissions.

Objective 3: With defined CO_2e emissions for the original/new seasonal calendar, various biofuel will be researched and implemented in all three modes of transport.New fuel emissions will then be calculated and compared to original CO_2e emissions, highlighting potential improvements of alternative fuel adoption. Further investigation will then confirm or deny whether these alternative fuel improvements are achievable within the near future.

Chapter 2

Background

F1 in a broader scope is encompassed within the motorsport category, which is viewed as extremely diverse from categories such as motorbikes to four-wheeled vehicles, further defined into sub-categories such as on-road or track racing. The commonality between all motorsports is the competitive aspect where all participants strive to win, alongside the dependence on physical resource provided by from fossil fuel; mainly crude oil for propulsion in early years. [6] As previously mentioned the global governing body for motorsport is the FIA established in 1975, whom state they are the "sole international sporting authority entitled to make and enforce regulations based on the fundamental principles of safety and sporting fairness, for the encouragement and control of automobile competitions". Within their International Sporting Code (2020) they fail to define the term 'motorsport' however they do define what they believe to be an 'automobile':

"Vehicle running in constant contact with the ground (or ice) on at least four non-aligned wheels, of which at least two are used for steering and at least two for propulsion; the propulsion and steering of which are constantly and entirely controlled by a driver on board the vehicle (other terms including but not limited to car, truck, and kart may be used interchangeably with Automobile, as appropriate within types of competition)." [7]

The regulations set by the institution align with current technological innovations, enabling the cars access to faster speeds. For example, mid 1980's turbo engines experienced over 100 bhp (brake horsepower), following this engine revolutions reached a maximum in 2006 at 19000 rpm and then restricted to 18000 rpm in 2009 onward. [6] Materials at this time were also being placed under severe restrictions, meaning engine designs were fairly similar from 2007 onwards, since manufacturers were using the same suppliers. The global financial crisis then hit in 2008 causing the FIA to re-examine their regulations, as manufacturers were unable to afford the high costs associated with F1, therefore in 2009 kinetic energy recovery systems (KERS) were acceptable; showcasing an energy capacity of 400kJ and a maximum power of 60kW. Initially the new regulation for KERS had no effect on the performance of the cars so were not incorporated but became extremely popular in 2013 and became a requirement in 2014. [8] The increased power and energy unit (KERS) was then renamed Motor Generator Unit-Kinetic (MGU-K) and a Motor Generator Unit-Heat (MGU-H) joined to the turbocharger shaft. Here fuel flow restrictions were also brought in, limiting the engine to 100 kg/h. In addition to this, the number of engines were restricted per season, and the development of engines declined. These further limitations and restrictions were seen as attractive to commercial partners however at the expense of an engineer's freedom to innovate. In order to achieve maximum performance the main contributor became the engines efficiency. [9] In terms of specific teams engine designs and adaptations they are usually kept private and confidential, particularly those that would provide advantageous to opposing competitors. Any data found has either been leaked or been made generally available to the public by the engine manufactures. [10]

The sport, as mentioned previously is viewed by over 500 million fans globally therefore it is used extensively as a marketing tool for maintaining, strengthening and building a brands image. The event comfortably competes with figures associated with the FIFA World Cup or the Olympic Games, therefore its understandable why large international companies utilise the sport as an advertising platform. Sponsorship money is predominantly used to finance the F1 Circuit while TV broadcasting and entrance fees are seen as minor importance. In the early days the sports main source of sponsorship was from the tobacco industry however after the European Union ban this, from 2006 onwards companies such as Emirates, Red Bull and Intel stepped up. [11] Sponsorship nowadays comprises of team sponsorship, trackside advertisement, series partnerships and team owners payments. In 2018 team sponsorship accounted for 44.7% of F1's total haul, with majority being from title sponsors whom get naming rights and their name plastered on the cars most visible parts. For example Aston Martins partnership deal with Red Bull, alongside Sauber's partnership with Alfa Romeo. Second largest investment is from team owners which represented 38.9% in 2018 followed by 12.6% from the sports series partners. There are 16 partners currently, with global partners ranking the highest in terms of importance, these for example are brands such as Rolex and Heineken whom respectively pay annual fees of approximately $45 million and $50 million to the sport. The total estimated sponsorship figure in 2018 was $1.7 billion. Greater sponsorship is an additional bonus to the teams with winning succession therefore the losing teams struggle to compete financially as they do not have the same funding opportunities available to them. [12]

Some of the teams currently competing are, MacLaren, HAAS F1 team, Red Bull Racing, Scuderia Ferrari and Mercedes AMG Petronas F1 team, with drivers such as; Sebastian Vettel, Daniel Ricciardo, Max Verstappen and 6th time world champion Lewis Hamilton. Seven out of the ten teams competing are based in the United Kingdom (UK), so it is a major industry for the country. The sport is estimated to employ over 40,000 staff members over the racing industry and generate an annual turnover of around £9bn, with £1bn invested into research and development. [13]

Liberty Media stated that in 2019 there were 4.2 million spectators over the season, averaging around 198,000 attendees per race. In addition, the series is broadcast in nearly 200 territories worldwide by Live Nation Entertainment Inc, resulting in a cumulative audience of 1.92 billion. [2] From this it is apparent the sport is not slowing down anytime soon; its demand and season is growing year in year out therefore their emissions should not be discarded given the current climate situation. Their strategic sustainability plan was not supported by everyone however it looks at the longevity and future of the sport, influencing and securing F1's future prospects. Financially the sport is at an advantage, allowing their action plan to be initiated quickly, therefore if the strategic plan is implemented and achieved they could change not only the future of F1 but the future of the transportation industry as a whole.

Chapter 3

Formula 1 Environmental Impact

Liberty Media undertook an investigation in 2019 to examine the sports carbon footprint over one entire race season, as a result approximately 256,000 tonnes of CO_2e was generated. This results was further broken down into the sectors of the sport responsible; event operations, facilities and factories, business travel, logistics and finally the power unit emissions. Shown below in Figure 3.1 highlights the carbon footprint created per sector:

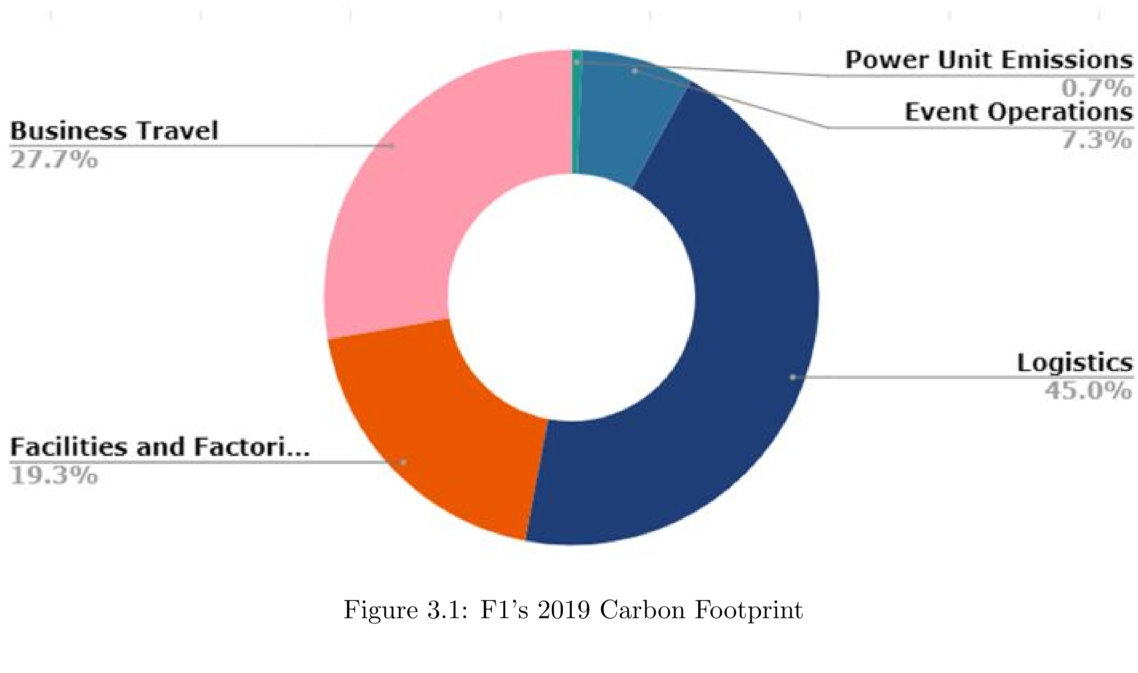

Figure 3.1: F1's 2019 Carbon Footprint

The power unit sector encompasses all emissions related to the fuel usage of all power units across the ten teams during all twenty one Grand Prix races, including pre-, mid- and post-season testing. The event operations value relates to all the event impacts, including Paddock Club operations, support races, broadcasting, circuit energy use, teams at circuits impacts (excluding power unit emissions) and generator use. The logistics sector includes all air, sea or road logistics associated to the transportation of team equipment, F1 equipment, Paddock Club equipment and race tyres. Business travel emissions account for the transportation (both air and ground) of all individuals, alongside hotel impact for all F1 teams employees and major event partners employees. Finally the facilities and factories emissions justify all offices or facilities operated by F1, including all team operated offices, facilities and factories.

From Figure 3.1 the emitting sector of most concern is logistics, responsible for 45% of F1's carbon footprint. Following this, business travel responsible for 27.7% and facilities and factories 19.3%, the event operations and power unit emissions do not appear as concerning when compared to the other sectors overall however they still emit 1,796 tonnes and 18,728 tonnes respectively which cannot be overlooked. As stated previously the sports aims to tackle their proposed plan in two stages with deadlines of 2025 and 2030.

Initially the sport strives to be sustainable by 2025, saying they want to *'leave a legacy of positive change wherever we race'* with the motto of 'Positive Race Print'. Their intermediate goal aspires to enrich communities and economies alongside supporting the natural surrounding environment whilst ensuring the F1 series qualifies as a sustainable spectacle. [14] F1's sustainability plan aims to achieve this definition by implementing the four following methods. Firstly all event waste will either be reused, recycled or composted enforcing only compostable or recyclable material use, such as zero single-use plastic, within the events. This will be measured by the percentage of waste by weight that is either re-used, recycled or composited and the percentage of materials that are recyclable or compostable. Secondly, incentives will be promoted to fans enabling them to travel to a race location with lower/zero carbon footprint, or alternatively methods to offset emissions created by their travel. The percentage of passengers travelling by public transport, bike/foot or plug-in hybrid electric vehicle/electric vehicle will be measured alongside the percentage of remaining emissions from offset travel. Thirdly, by 2025 events also aim to enhance biodiversity, offer healthier food alternatives and improve air quality , improving not only the local environment but fans wellbeing. They will measure the percentage of F1 approved fan wellbeing and biodiversity action plan. Finally the sport wants to build partnerships that engage local people, providing greater access to the events and showcasing local businesses who want to get involved. A balanced scorecard will be used as measurement for local community engagement.

The second stage follows the motto 'Countdown to Zero' where the sport will achieve net zero carbon emissions from factory to flag by 2030. This final goal of the strategic plan aims to systematically reduce CO_2e emissions created by the events, operations, race cars and logistics. On the track the sport intends to put F1 at the forefront of the automotive sector, producing the world's most efficient and powerful race cars driven by hybrid power units fuelled sustainably. The weight (kg) of CO_2e created per litre of fuel used will be recorded for measurement, indicating the improvement of reduced emissions. On the move logistics need to be maximised alongside travelling efficiency by optimisation of the process and volume of equipment/staff transported, the plan is to achieve this using the least CO_2e intensive transportation option available. For analysis the tonnes of CO_2e generated per km will be taken as measurement. In addition all F1 facilities, factories and venues including team facilities, aim to be 100% renewably powered in terms of electricity through adopting net zero carbon technologies for heating, ventilation, air conditioning and mobile power. Measurement will be of the percentage of renewable electricity generated via power purchase agreement and compared to the original systems currently in place. Lastly F1 state that for any unavoidable emissions, they will be fully offset through the use of verified biological and technical sequestration programmes. Here the total tonnes of CO_2e captured though carbon sequestration programmes will be measured for analysis. [14]

All of these factors when implemented should then reduce the overall carbon footprint of F1 by lowering the carbon generation per individual sector, specifically the larger emitting sectors such as the logistics.

Chapter 4

Literature Review

If F1 want to achieve net-zero carbon emissions by 2030, several publications were researched and included in the references, all agreeing there is imminent need for change within the sport. The publications acknowledge F1's constant evolution, and the progress the sporting event has made, not only on-track but off-track, yet with the world's current climate crisis the sport needs to make this the main focus moving forward. Understandably the sport's governing body (the FIA) aim to sustain a high level of competition, captivating an annual audience but regulations and policies need to be implemented to ensure sustainability of the events is reached and adhered to. [3] With F1 being the forefront of automotive innovation, carbon mitigation technologies have the potential to develop and progress, whilst being showcased on a global platform. For example, current F1 cars run on hybrid power units making them the most efficient cars to date, if sustainable fuels and energy recovery systems are incorporated there is potential for a net-zero hybrid power unit, which then has the potential to correlate to internal combustion engines globally. The sports partners, sponsors, organisers and teams are onboard with the strategic sustainability plan, with many already practicing sustainable measures within their own factories and facilities. These initiatives now have to be applied elsewhere, for example logistics and event operations. [4] In addition, if F1 pave the way for sustainable motorsport, it can be easily reflected in other motor sporting categories such as Indy Car and Superbikes etc. [6]

For F1 the largest emitting sector is logistics, transporting equipment between international and European races is increasing anthropogenic emissions substantially. In terms of freight transportation the global share of emissions continues to grow; compared to any country (except USA) the international shipping and aviation industry generate greater CO_2 emissions per year. [24] The transportation sector is globally responsible for 14% of greenhouse gas (GHG) emissions with freight transportation (defined by rail, truck, air and marine movement) responsible for 6%. Based on the global freight demand trend, from 2015 to 2050 the trade is expected to triple in size, therefore freight is an important sector for climate mitigation, with implementation of climate policy required to achieve this shift to low-carbon transport. Different approaches have been highlighted specifically to address reducing freight impact such as: reduced GHG emissions associated with fuel, improvement in engine technologies, freight activity reduction and utilising less emission intensive methods of transport. In terms of policy changes these could be in the form of carbon tax, which is a recommended technology neutral approach and could influence users to uptake some of the more GHG reducing approaches mentioned. Another strategy could be a low-carbon fuel standard where fuel suppliers are forced to reduced the average carbon intensity within their fuel; for example a blend of bio-fuels with conventional fuels or reducing their emission during fuel production.

For the aviation sector, the International Civil Aviation Organization (ICAO) in 2016 announced the sectors plan to reduce GHG emissions starting 2021. This proposal gained support from 66 nations whom account for 86% of the sectors activity, combining operational and technical improvements with backing for sustainable aviation fuel production and use. Boeing and Airbus are currently leading the efforts in the development of bio-jet fuel. Current freight emissions contributed by the aviation sector are significantly small, the improvements suggested will not drastically reduce the sectors emissions, however their minor reductions contribute to a greater global action plan. [28] Research papers found in the reference section [47–53] highlight the research and development being undertaken in aviation biofuel. From bioethanol and synthetic paraffinic kerosene (SPK) being two examples investigated within this paper, the potential for numerous alternative aviation is significantly growing. The criteria for acceptable aviation biofuel is stringent, firstly it requires certification in accordance to the industry's performance and safety requirements, it must be a 'drop-in' alternative to ensure large costs are avoided in terms of aircraft modifications or restructure and finally a material reduction in lifecycle carbon emissions must be achieved when compared to conventional fossil-based jet fuel. Even with this promoted "green" solution, the quantity of fuel required is still not manageable to produce. Concerns arise with biofuel crop production as people fear this will overtake food production land and increase the price of foods. Therefore other feedstock means are under investigation such as animal and municipal waste. [47]

A quarter of freight emissions are linked to international shipping, with vessels transporting 70% of global freight life; the industry is integral to the global economy. In terms of environmental sustainability, this transport sector also proves challenging. Compared to other modes of transportation such as trucking, rail or air, shipping by vessels produces less emissions per tonne of cargo. The financial cost is also minimal compared to the percentage of total cost of goods sold, therefore change appears unnecessary. However the marine sector still carries a responsibility to the global GHG contribution therefore cannot be overlooked. The International Maritime Organization (IMO) stated the sea trade in comparison to air travel has double the carbon footprint, contributing an estimated 2.7% to the global CO_2 emissions. Improvements have been witnessed by the shipping industry already with some carriers adopting slow steaming practices; improving the existing ships fuel efficiency and therefore reducing emissions. Privately led green shipping organizations have also became popular, such as Sustainable Shipping Initiative (SSI) and the Clean Cargo Working Group (CCWG). Both aim to collaborate with companies to educate, demonstrate and establish better practice in maritime shipping, in the hope to eventually gain better sustainable practices. SSI pursues broader initiatives to illustrate a sustainable pathway moving forward for the sector, whereas CCWG is heavily technical driven, focusing on developing measurement tools to assess environmental performance in terms of reduced carbon emissions. [29] Studies such as [41, 43–46] are investigating the use of alternative marine fuels, such as methanol and ammonia. In the short term, to decarbonise the maritime sector, green ammonia proves the most technically feasible. However evidence indicates it is very costly to produce therefore, policies or subsidies from the government need to be enabled to kick start large scale production. [44] Methanol is much safer, reliable fuel, for marine life and fuel handling with global availability extremely high due to its use in the chemical industry. Costs of this fuel are also low, the issue faced is the lack of specific marine fuel infrastructure in place for its adoption. [41] The marine sector also acknowledges design upgrades on vessels are needed to reduce the fuel consumption, in return cutting emissions. [42]

For surface freight, transported mainly by road services and rail services, its business is utilised majorly across global regions due to its convenience and competitiveness. From the year 2000 to 2015 its demand was highlighted by a 40% growth in the market. A road fleet typically consists of light-commercial vehicles through to medium and heavy trucks; with majority of the F1 fleet being heavy diesel powered trucks. [24] The Smart Freight Centre (SFC) a global non-profit organization, established in 2013, stated road freight emissions account for two thirds of the global freight emissions and therefore by establishing sustainable plans and projects for this sector backed by operators support, the GHG emissions will be cut massively. [30] The sustainability of road transport is researched in [31–36] with the aid of biofuel, this report focused on LNG and bioethanol but the road transport has many other option available. Bioethanol has the flexibility to be produced by various feedstock, therefore its feasibility in global scale production is positive. Issues and challenges are still faced alike many other biofuel therefore these need to be addressed before commercial adoption; for example the technical and economic issues faced in cellulosic ethanol production. [36] LNG adoption demonstrates low cost and extreme benefits if utilised within the road transport sector, the drawback is the poor development of production, transportation and refuelling infrastructure. [33]

DHL, F1's official logistics partner, announced their sustainability plan in 2019, stating their aim to achieve net zero emissions by 2050, with sustainability being an integral benchmark by 2025. This works in F1's favour as it coincides with their 2025 sustainability plan. The plan appears ambitious considering DHL are only responsible for 0.4% of the global GHG emissions within the transportation sector, however the company is set to *to "pave the way for sustainable logistics"* with the projection that all logistic-related emissions will be reduced to net-zero. The company have already displayed initial success with their energy efficiency gains, both in ocean and road freight alongside the implementation of green electricity within their sites. Four new aircraft have replaced older aircraft in the fleet, which will reportedly reduce carbon emissions by 18% and improve fuel and emission efficiency. Over 13,000 road vehicles have installed alternative-drive systems, however DHL state the biggest challenge remains within medium and long-haul services as electric vehicles are not yet feasible. They hope to implement sustainable fuels over the next 10-20 years to combat this and majorly reduce the GHG emissions, alongside improving their fleets engine efficiencies. This is included in their Group-wide GoGreen program, which targets both DHL's direct and indirect carbon emissions. [31] Figure 4.1 below illustrates the companies 2050 mission and interim targets for 2025.

Figure 4.1: DHL's Mission 2050 and Interim Targets for 2025

Chapter 5

Current Logistics

With logistics being the largest carbon emitter, the sport has many challenges associated to reducing this impact and ensuring a exciting Grand Prix season is maintained. As stated the logistics sector encompasses all transportation of team equipment, race tyres, F1 equipment, Paddock Club equipment, and broadcasting equipment. This is undertaken by airways, waterways and roadways to all twenty one Grand Prix's across five continents. DHL are the Official Logistics Partner of F1 handling the complex, and time-critical motorsport logistics to ensure reliable delivery for the start of each race. Achieved through detailed planning of the global complex routing. Whilst competing in Europe teams normally operate their own purpose-built transporters and vehicles, with support from leading freight organisations, to circulate their own equipment and car to race weekends. Alongside transporting equipment to European races, the transporters are transformed into data-management suites, workshops, executive suites and a range of meeting rooms. Even with the numerous team transporters residing within the main paddock area, they are all perfectly aligned and thoroughly cleaned to ensure complete professionalism is maintained from the outlook. [15] The transporter trucks are absent from 'flyaway' races, such as the Australian Grand Prix in Melbourne, so the paddock is arranged slightly differently, however the level of equipment remains constant for each team. For 'flyaway' races, air and sea freight is required which DHL are responsible for, in 2018 the company reported 660 tons and 500 tons were transported for airfreight and sea freight respectively, with 131,995km travelled by six Boeing 747 planes during the season. [16] As a spectator watching a Grand Prix weekend, everything you see from pit lanes, garages and paddock has to be packaged, cleared by customs on both departure and entry, delivered and set up at a new circuit, then repacked and shipped back to UK base or next Grand Prix. The usual time frame to achieve this is two weeks which can prove difficult, however some races are undertaken on back-to-back weekends, emphasising the complexity of logistics for F1.

The Grand Prix season operates from March to late November with 21 races spread across 9 months. The 2019 season calendar is shown below in Table 5.1. The current timetable lacks efficiency as European races are not conducted on neighbouring weekends, which would ensure road transportation is used between them, reducing air and sea emissions. Instead Spain and Monaco races are carried out on adjacent weekends with the Canadian Grand Prix following after, rather than a European race of closer proximity. Thus highlighting the current timetables inefficiency from a economic and environmental point of view. The 2020 seasonal calendar introduced a new race in Vietnam, totalling the season to a record of 22 races, therefore the complexity of F1 logistics is not slowing down.

Table 5.1: The 2019 Grand Prix Season Calendar

Round	**Race**	**Circuit**	**Date**
1	Australia	Albert Park	March 15th - 17th
2	Bahrain	Bahrain International Circuit	March 29th - 31st
3	China	Shanghai International Circuit	April 12th - 14th
4	Azerbaijan	Baku City Centre	April 26th - 28th
5	Spain	Circuit de Catalunya	May 10th - 12th
6	Monaco	Monaco	May 23rd - 26th
7	Canada	Circuit Gilles Villeneuve	June 7th - 9th
8	France	Paul Ricard	June 21st - 23rd
9	Austria	Red Bull Ring	June 28th - 30th
10	UK	Silverstone	July 12th - 14th
11	Germany	Hockenheimring	July 26th - 28th
12	Hungary	Hungaroring	August 2nd - 4th
13	Belgium	Spa-Francorchamps	August 30th - September 1st
14	Italy	Monza	September 6th - 8th
15	Singapore	Sinapore	September 20th - 22nd
16	Russia	Sochi Autodrom	September 27th - 29th
17	Japan	Suzuka	October 11th - 13th
18	Mexico	Autodromo	October 25th - 27th
19	USA	Circuit of the Americas	November 1st - 3rd
20	Brazil	Interlagos	November 15th - 17th
21	Abu Dhabi	Yas Marina	November 29th - December 1st

Currently all F1 teams reside in Europe so any freight flying internationally is departed from London or Munich, with all the European races conducted by road transport. The breakdown of equipment for European race weekends shows cars, spare parts and tools are transported by the teams own vehicles with fuel, tyres and other equipment separately transported by technical contractors and local partners. To ensure no damage is caused to the car, it is cushioned and placed on an elevated platform, with all aero packaging removed. For 'flyaway' races the challenges start to arise, initially the parts are categorized into critical and non-critical categories. For instance chassis, tires, engines, computers, IT racks and wings are classified under critical components. Items found in the garage such as jacks and tools etc are classified as non-critical. These non-critical components utilize sea transport and usually ensure multiple sets are available for shipment well in advance; guaranteeing teams receive it on time since sea freight has a slower delivery period. Critical components are flown to races by DHL cargo planes with the cars completely stripped down, for example the engine and gearbox alongside mirrors and suspension etc are removed, before being transported. Teams have their own customer cargo packaging to allow optimum use of space in the plane. For special cases, such as back-to-back 'flyaway' races, additional equipment is packed and transported as direct transit is required; securing smooth operation. [18] Highlighted below in Figure 5.1, is an example of Red Bull racing teams packaging for air and sea cargo, travelling from Shanghai to Bahrain:

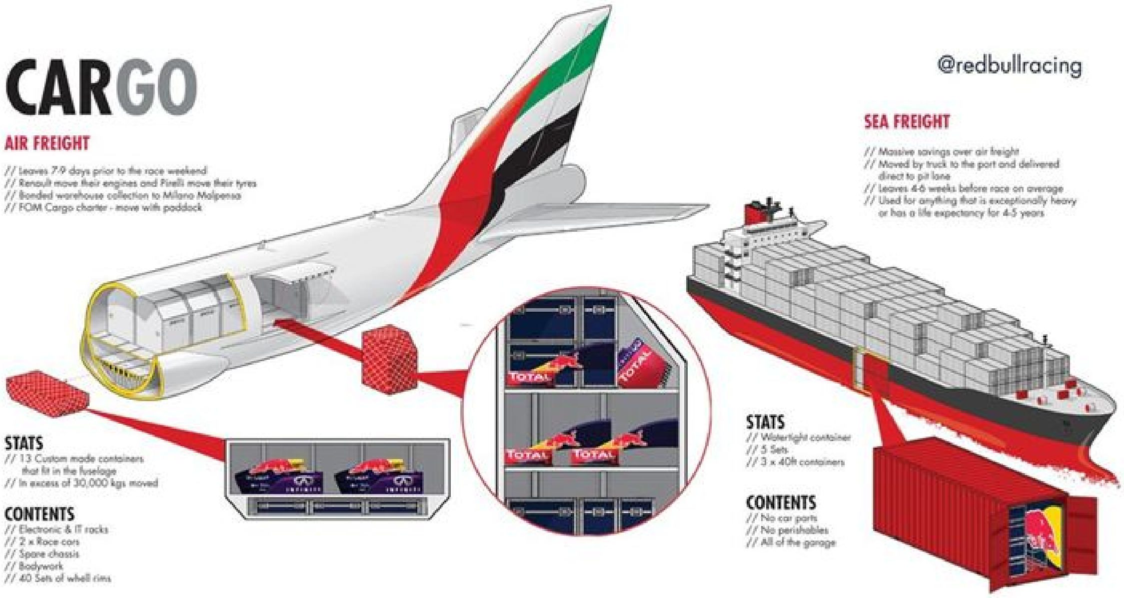

Figure 5.1: Red Bull Racing Airfreight and Sea Freight. [19]

This image was published by 'Aston Martin Red Bull Racing' on their social media platforms in 2015. Air freight is stated to be flown 7-9 days prior to a race weekend with Renault and Pirelli, the engine and tyre suppliers in 2015, respectively transporting these parts. Their thirteen custom fit containers contain two race cars, spare chassis, the bodywork, forty sets of wheel rims and all electronic and IT racks. Figure 5.1 also exhibits how the freight is stored in the fuselage. Sea freight is transported around 4-6 weeks prior to a race weekend and is for non-critical parts with life expectancy of 4-5 years, or parts that are exceptionally heavy. A truck transports the equipments to the port and then to the pit lane after shipping. Red bull state their sea freight includes five sets of 3x40ft watertight containers, housing all of the garage equipment with no car parts or perishables. [19]

5.1 Methodology

5.1.1 Road Freight Emissions

The European Grand prix races as previously stated are reached by road transport, the following section analyses the potential CO_2e emissions. Data is not available for the individual truck journey or number of trucks used by each team, therefore assumptions are made such as the route selected and which destinations are reached by road transport. All calculations and assumptions are based on the 2019 Grand Prix season calendar. The following journeys in Table 5.2 are assumed to be undertaken by road transport and the corresponding distance between each venue shown:

Table 5.2: 2019 Road Freight Distances

Road Freight Journey	**Distance (km)**
Spain - Monaco	686
France - Austria	1130
Austria - UK	1579
UK - Germany	580
Germany - Hungary	953
Hungary - Belgium	1219
Belgium - Italy	765

In order to calculate the CO_2e emissions equivalent for one truck, Equation 5.1 was used:

$$CO_2e(g) = d.X.LHV.Y \tag{5.1}$$

where:

d = Mileage (km)

X = Fuel Consumption (l/km)

LHV = Lower Heating Value (MJ/l)

Y = Diesel GHG Emissions (gCO_2e/MJ)

Output of Equation 5.1 then converted into tonnes of CO_2e.

To calculate the emissions for the diesel trucks the following specifications were used:

Average Diesel Fuel Consumption (l/km) = 0.3

Diesel Lower Heating Value (MJ/l) = 36

Diesel GHG Emissions (gCO_2e/MJ) = 262 [20]

5.1.2 Sea Freight Emissions

The remaining races spread around the world ship large volumes of freight; specifically non-critical components. As DHL stated in 2018, 500 tonnes of freight. Each team reported to ship 45 tonnes of equipment via shipping alongside 10 tonnes of electronics. In addition, F1 utilise shipping for their hospitality equipment, estimated at around 460 tonnes, and broadcasting equipment estimated at 150 tonnes. [16] To calculate the CO_2e emissions emitted during a ships journey, DHL provide a 'Carbon Calculator' which operates from the following inputs; cargo total weight, starting destination, final destination and if the shipment is to be assigned to its own dedicated ship or transported with cargo of similar destinations. Provided with this data the software automatically selects the optimum route, accounting for pre and post transport runs alongside gateways and hubs. DHL state the emissions calculated during the cargos journey are based on their internal transport and efficiency data. The tool follows the standards of the Greenhouse Gas Protocol and the European Standard EN16258, with an emission factor (EF) obtained from the BSR Clean Cargo Working group. The group accounts for different vessel types, region-to-region EF's, different load types, speeds, weather conditions etc. The value they provide encompasses all mentioned factors and generates an EF based on previous routes used on a given ocean lane. The emissions generated are Well-to-Wheel (WTW) emissions as its value encompasses the products lifespan and the overall greenhouse gas emissions generated throughout. [23] [21]

5.1.3 Air Freight Emissions

Critical components are then flown between races, compared to shipping freight and surface transport, aviation emissions have a much greater CO_2 intensity as the particles emitted remain in the atmosphere at higher altitudes, for longer periods of time before they break down. [24] To calculate these emissions various factors are required to understand the total CO_2e emitted per flight. The weight (kg) of CO_2e per tonne-kilometre is represented by the EF, and used to calculate the final $kgCO_2e$ emitted. Therefore the distance is required as the tonne-kilometre represents the change of one tonne weight over one kilometre. Distance between the original and desired destination is calculated using the Great Circle Distance (GCD) formula shown by Equation 5.2. The GCD represents the shortest distance between two points on a spheres surface; also described as the direct distance. This calculation method is frequently adopted by the aviation industry.

$$d = 2.r.arcsin.\sqrt{(sin^2\frac{lat2 - lat1}{2}) + cos(lat1).cos(lat2).sin^2(\frac{long2 - long1}{2})} \tag{5.2}$$

where:

d = Total Distance (km)

r = Earths Radius (6378.137 km)

lat1 & lat2 = Latitude of origin and destination in radians respectively

long1 & long2 = Longitude of origin and destination in radians respectively

In an ideal case the GDC distance would be the only requirement, however a flight may experience deviations especially at take-off and landing, therefore to compensate a 'detour' distance is added. This extra distance accounts for traffic, weather associated corrections and emissions of stacking. The additional detour value calculated using Equation 5.3, with the GDC expressed in terms of 1,000km, and total distance calculated by Equation 5.4 :

$$Detour(km) = 63.472.GDC^{0.4564} \tag{5.3}$$

$$TotalDistance(km) = d + detour \tag{5.4}$$

Next step is to obtain total weight of the aircraft and shipment, including everything from the weight of containers, pallets, in addition to handling and security devices of the cargo being transported. The 2018 DHL recorded freight weight will be used alongside the weight of a Boeing 747 plane; DHL recorded as their air freight carrier for F1. The aircraft is assumed to be the Boeing 747-400F aircraft. Therefore the values are 660 tonnes and 396.89 tonnes for freight and aircraft weight respectively. [25] The total weight used in the calculations was 1057 tonnes.

After this an EF is determined based on the load factor of the plane and aircraft type. For each aircraft a 65% average load factor is assumed. The following table below (Table 5.3) is used to establish the EF and presents airfreight emission data influenced by the aircraft range and includes the WTW emission factors; encompassing energy use from fuel production to distribution and combustion. This data was collected from the Network for Transport Measures. [26]

Table 5.3: Average emissions factors for airfreight

Aircraft Range	**Distance Range (km)**	**Aircraft Type**	**WTW CO_2e (kg/tkm)**
Regional	< 785	Freight	2.10
Continental	785 – 3,600	Freight	0.92
Intercontinental	$> 3,600$	Freight	0.58

Final step is to calculate emissions produced during the flight using Equation 5.5 [27];

$$CO_2e(kg) = TD.W.EF \tag{5.5}$$

where:

TD = Total Distance (km)

W = Weight (tonne)

EF = Emissions Factor (kg/tkm)

To stay concise with sea and road transport, final weight is converted into tonnes. As the EF is dependent on several factors such as shipment distance and vehicle type, emissions need to be calculated separately for each journey and added together to generate total emissions. For these calculations only the air freight emissions are considered, road travel pre and post flight is not.

5.2 Results

5.2.1 Road Freight

For road transportation the CO_2e emissions are highlighted in Table 5.4 below:

Table 5.4: CO_2e Emission for Road Transport

Road Freight Journey	**WTW CO_2e (tonne) per truck**
Spain - Monaco	1.94
France - Austria	3.20
Austria - UK	4.47
UK - Germany	1.64
Germany - Hungary	2.70
Hungary - Belgium	3.45
Belgium - Italy	2.16

Therefore one truck completing every journey would produce of **19.56 tonnes** CO_2e. If for example, each team utilized 30 trucks the total theoretical CO_2e emissions produced by road transportation would be **5867.46 tonnes**.

5.2.2 Sea Freight

For sea freight the carbon calculator produced CO_2e emissions shown in Table 5.5. The weight input being 500 tonnes with the requirement for the shipment to be assigned to an individual ship.

Table 5.5: CO_2e Emission for Sea Transport [22]

Sea Freight Journey	**Distance (km)**	**WTW CO_2e (tonne)**
UK - Australia	23,955	134.55
Australia - Bahrain	14,844	93.76
Bahrain - China	12,653	50.02
China - Azerbaijan	5,459	84.64
Azerbaijan - Spain	5,459	58.37
Monaco - Canada	9,042	49.17
Canada - France	9,244	47.70
Italy - Singapore	14,185	51.03
Singapore - Russia	14,185	54.74
Russia - Japan	20,442	79.35
Japan - Mexico	22,417	99.50
Mexico - USA	2,193	31.32
USA - Brazil	12.743	75.02
Brazil - Abu Dhabi	18,171	115.53

The optimal distance for each trip is given alongside the WTW CO_2e emissions. The total emissions generated by shipment of all equipment is **1,025 tonnes**.

5.2.3 Air Freight

Finally by using Equation 5.3 in addition to Equation 5.4, the total distances for air freight were calculated. Following this, CO_2e emissions per flight were calculated using the respected EF value located in Table 5.3 , alongside the total weight. Results for air freight emissions and distance generated per flight are presented in the following Table 5.6:

Table 5.6: CO_2e Emission for Air Transport

Air Freight Journey	**Distance (km)**	**WTW CO_2e (tonne)**
UK - Australia	17,162	10,520
Australia - Bahrain	12,312	7,547
Bahrain - China	7,004	4,293
China - Azerbaijan	6,532	4,034
Azerbaijan - Spain	4,105	2,517
Monaco - Canada	6,292	3,857
Canada - France	6,157	3,774
Italy - Singapore	10,462	6,413
Singapore - Russia	8,009	4,910
Russia - Japan	8,090	4,959
Japan - Mexico	11,783	7,223
Mexico - USA	1,275	1,240
USA - Brazil	8,263	5,065
Brazil - Abu Dhabi	12,358	7,575
Abu Dhabi - UK	5,737	3,517

The estimated air freight emissions produced by F1 in 2019 being **77,414 tonne**. This value only demonstrates the aircraft flight emissions, as stated pre or post flight road transport is not included as only concerned with flight impact.

In conclusion, F1 current logistics produced a CO_2e total of 78,459 tonne, in the 2019 Grand Prix season.

5.3 Discussion

Official records from Liberty Media state F1 logistics emit 115,200 tonne of CO_2e, which is greater than the calculated emissions (78,459 tonne). This discrepancy is associated to many different factors; firstly for all sea and air transport emissions calculated no pre or post road transport is included. This means transport emissions between dock/runway to race are ignored, here additional transport emissions would be associated to each journey. Alongside this, there is no available data detailing the number of transporters utilised by each team or F1. The calculated road transport emissions are associated to one truck therefore with this data available road transport emissions would be greater. Even the route taken by transporters is assumed, so the larger number stated by F1 owners in comparison to the calculated emissions is due to data availability. Greater emissions are experienced by air freight, with sea freight much lower if (as mentioned) 30 trucks were utilised by each team. Air freight CO_2 emissions have much higher intensities compared to road or maritime, with maritime shipping CO_2 having lower intensities than road. This idealistically would influence maritime freight to be used more however with F1's time constraints between races, it is not feasible or reliable for the sport to do this. [24]

With the current Grand Prix seasonal calendar, it is understandable why the F1 logistics sector produces the greatest emissions, air and maritime freight is relied upon heavily, with great distances travelled, and many race weekends forcing delivery routes to double back on themselves. This being extremely inefficient for the methods of transport, not only environmentally but economically. Future logistics could potentially utilise rail freight services, this sector proves easier than air and maritime transport to electrify or run on alternative fuel therefore F1 logistics emissions could be heavily reduced.

Chapter 6

Alternative F1 Logistics

For F1's case, one of the more obvious solutions to reduce carbon emissions is to rearrange the seasonal calendar to a more efficient travelling layout. This includes clustering all European races on adjacent race weekends so road transportation is the main method of travel. International races also undertaken at closer proximity to the last race enabling shorter distances travelled by air and ocean freight. Concerns arise regarding the climate conditions during the race, currently the seasonal calendar ensures drivers are not driving in extremely hot or cold conditions; for example the Singapore Grand Prix is conducted at night to ensure cooler conditions. This means a change in seasonal calendar must also ensure this element of climate conditions are considered so races are not cancelled. The new proposed rescheduled Grand Prix calendar is shown in Table 6.1, with additional columns highlighting the conditions experienced that time of year. Here an updated version of the 2019 Grand Prix seasonal calendar with a more efficient layout is possible. This new proposal would ensure efficient travel for all modes of transport.

Table 6.1: Alternative 2019 Grand Prix Season Calendar

Round	**Race**	**Date**	**Climate**	**High/Low (°C)**	**Transport Mode**
1	Azerbaijan	Mar 15th - 17th	Windy/Dry/Chilly	9.8/4.2	Fly from UK
2	Bahrain	Mar 29th - 31st	Cool/Sunny	25/18	Drive
3	Abu Dhabi	Apr 12th - 14th	Warm/Dry	34/22	Drive
4	Japan	Apr 26th - 28th	Rain	19/8	Fly
5	China	May 10th - 12th	Mild (spring)	24/17	Fly
6	Singapore	May 23rd - 26th	Warm/Tropical	32/26	Fly
7	Australia	Jun 7th - 9th	Cool (winter)	15/8	Fly
8	Brazil	Jun 21st - 23rd	Cool/Dry	25/19	Fly
9	Mexico	Jun 28th - 30th	Warm/Dry	26/7	Fly
10	USA	Jul 12th - 14th	Hot/Humid	35/24	Fly
11	Canada	Jul 26th - 28th	Mild	26/18	Fly
12	Spain	Aug 2nd - 4th	Hot/Humid	35/24	Fly
13	France	Aug 30th - Sept 1st	Warm/Dry	25/18	Drive
14	Monaco	Sept 6th - 8th	Mild	24/19	Drive
15	Italy	Sept 20th - 22nd	Warm/Relatively Dry	24/16	Drive
16	Austria	Sept 27th - 29th	Warm	19/7	Drive
17	Hungary	Oct 11th - 13th	Mild	16/8	Drive
18	Russia	Oct 25th - 27th	Mild/Rain	20/12	Drive
19	Germany	Nov 1st - 3rd	Chilly	9/3	Drive
20	Belgium	Nov 15th - 17th	Cold/Rain	7/3	Drive
21	UK	Nov 29th - Dec 1st	Cold/Mild/Rain	8/6	Drive

Not every destination can experience optimal climate conditions however this new layout proves the most effective. Abu Dhabi, with the highest temperature experienced during the day being 25 °C, will be conducted during night time to ensure cooler conditions. Japan experiences rain majority of the year so it is unavoidable in this case. Here, truck transportation between Azerbaijan, Bahrain and Abu Dhabi is also feasible as they are in close proximity to each other. All races that require truck transportation still have sufficient time intervals between race weekends. Another advantage being the Grand Prix finishes in the UK, therefore majority of teams do not need to fly or ship their equipment back to their home factories.

6.1 Methodology

The same calculation techniques from Section 5.1 used for all three modes of transport, only a change to distances and additional road transportation utilised.

6.1.1 Road Freight

For alternative road transport emissions, Equation 5.1 adopted the new distances in Table 6.2.

Table 6.2: Alternate Road Transport Distances

Road Freight Journey	**Distance (km)**
Spain - France	555
France - Monaco	194
Monaco - Italy	337
Italy - Austria	638
Austria - Hungary	396
Hungary - Russia	2,316
Russia - Germany	3,110
Germany - Belgium	310
Belgium - UK	407
Azerbaijan - Bahrain	2,237
Bahrain - Abu Dhabi	821

6.1.2 Sea Freight

Shipping calculations generated by DHL's carbon calculator. All other specifications remained the same, only change made was the optimal route taken.

6.1.3 Air Freight

Calculations in Subsection 5.1.3 used, with the new distances calculated using Equation 5.2 and respected detour distance added. The corresponding EF used and new WTW CO_2e emissions generated.

6.2 Results

6.2.1 Road Freight

For alternate road transportation the following CO_2e emissions were calculated:

Table 6.3: Alternate CO_2e Emission for Sea Transport.

Road Freight Journey	WTW CO_2e (tonne) per truck
Spain - France	1.57
France - Monaco	0.55
Monaco - Italy	0.95
Italy - Austria	1.81
Austria - Hungary	1.12
Hungary - Russia	6.55
Russia - Germany	8.80
Germany - Belgium	0.88
Belgium - UK	1.15
Azerbaijan - Bahrain	6.33
Bahrain - Abu Dhabi	2.32

This new schedule generates **32.03 tonne** of CO_2e for one truck in the 2019 season.

6.2.2 Sea Freight

The shipping emissions show the following results in Table 6.4

Table 6.4: Alternate CO_2e Emission for Sea Transport. [22]

Sea Freight Journey	**Distance (km)**	WTW CO_2e (tonne)
UK - Azerbaijan	9,143	69.94
Abu Dhabi - Japan	13,920	58.58
Japan - China	2,018	16.32
China - Singapore	4,738	23.80
Singapore - Australia	8,817	43.37
Australia - Brazil	18,011	114.53
Brazil - Mexico	12,351	86.13
Mexico - USA	2,195	31.40
USA - Canada	8,054	79.60
Canada - Spain	8,881	45.55

Again, the optimal distance for each trip is given alongside the WTW CO_2e emissions. The new total WTW CO_2e emissions generated by shipment is **569 tonnes**. Showing a 44% improvement, with less journeys taken alongside an efficient route.

6.2.3 Air Freight

Finally alternate aircraft emissions show the following:

Table 6.5: Alternate CO_2e Emission for Air Transport.

Air Freight Journey	**Distance (km)**	WTW CO_2e (tonne)
UK - Azerbaijan	4,130	4,016
Abu Dhabi - Japan	7,979	7,758
Japan - China	1,534	3,405
China - Singapore	3,926	2,407
Singapore - Australia	6,185	3,791
Australia - Brazil	13,314	8,161
Brazil - Mexico	7,597	4,657
Mexico - USA	1,275	782
USA - Canada	2,785	2,708
Canada - Spain	6,062	5,895

Aircraft freight now generates **43,580 tonnes** of CO_2e; an improvement of 44% from original.

6.3 Discussion

Overall if F1 were to implement (this example) of an efficient timetable, the total overall CO_2e emissions would be estimated at (44,182 tonnes), reducing F1's CO_2e emissions by 44%, when compared to the initial calculated emission in Chapter 5.1. This quick fix can drastically reduce logistic emissions, plus it makes more sense geographically and economically. It may even influence fans to attend more races creating greater revenue for the sport. Utilising road transportation instead of air travel between races such as Abu Dhabi, Bahrain, Azerbaijan and all of the European leg produces less intense CO_2e emissions and equipment is still delivered on time. The new timetable does increase the use of road transport (by 36%), however CO_2e emissions here are significantly smaller in comparison to air and sea freight. Also green alternative solutions are more developed within the road transport sector, therefore CO_2e emissions can be further reduced if alternative fuels were implemented. Air freight still holds majority of the logistic emissions, even though flights have reduced by 44%. This is always going to be the case with the number of international races F1 conduct. If efficient flying routes and greener practices are implemented, carbon capture can be utilised to recycle the unavoidable emissions. As stated the aviation sectors emissions are significantly smaller than surface and maritime freight, with emissions at only 0.1% of global tonne-km, its mitigation efforts are appreciated but not of major concern in relation to surface freight. Another advantage is having the Silverstone Grand Prix as the final race weekend; since majority or teams are UK based, air and sea freight is not required to transport equipment back, compared to the original calendar which finished in Abu Dhabi.

A major concern is climate conditions for each race, optimum conditions are desired so race weekends are not cancelled so the alternative calendar encompasses this and rescheduled the calendar around this factor. Races will still be conducted at night time where extremely hot conditions are experienced during the day. For European races there is greater chance or rainier and colder conditions, however with places like the UK this is always a concern. On a side note, this schedule could prove beneficial (wellbeing) to the drivers as similar times zones are experienced; their sleep schedules are not changed so drastically.

Chapter 7

Biofuel

Evolving technologies are driving the future for clean generation, pushing the boundaries experienced today. Although major improvements within internal combustion engines have been achieved by improving the specific fuel consumption, reducing the fuel consumption, in turn reducing emissions. The growth of transport rapidly increasing, means the improvements made to the engine simply breakeven. This has enhanced the global need for alternative fuels, which will aid transports goal for low emissions. Europe shows general concern in terms of; the necessary infrastructure, the type of fuel required, technical and economic viability alongside the long term sustainability. However with evolution of environmentally friendly technologies many alternative fuels are making their way into market, especially those obtained from renewable sources. The range of substances classified as alternative fuels are:

1.*Electricity* - great potential for the implement of electric vehicles in countries where a large bulk of their electricity is generated by renewable energy sources. Their entire street network can provide charging infrastructure.

2.*Hydrogen* - produced by electrolysis of water or by breaking down the hydrocarbon in natural gas through steam reforming.

3.*Biofuels* - renewable transport fuel made from biomass material. Encompass different types such as biomethane, biodiesel, bioethanol etc. Some criticism over the economic and environmental cost of the refining process alongside the potential removal of large areas of land used for food production.

4.*Natural Gas: CNG (compressed natural gas) and LNG (liquefied natural gas)* - CNG does not require any additives or a complicated refining process when being made into a fuel. LNG is natural gas in liquid form.

5. *Liquefied petroleum gas (LPG)* - made from natural gas processing and oil refining.

Factors such as environmental requirements, local situation, political views and specific operations are considered when selecting the best technology. With the significant growth and development of alternative fuels in recent years the demand of upgraded infrastructure and accessibility will become more noticeable. [32]

7.1 Road Freight Biofuel

For long-haul journeys undertaken by F1's transporters, electric vehicles do not prove a viable solution as the electrical demand is deemed too high. The electric vehicles cannot travel the distances required. Hydrogen proves too costly to produce, limiting its wider application. Biofuel relies on land availability for production, proving unsecure in meeting the road transport sectors high demand, but not completely out of the question. The more favourable option for heavy duty trucks is LNG. Studies such as Arteconi et al. in 2009 and Ou and Zhang in 2013 highlight the environmental and economic benefits of using LNG as a fuel substitute, especially in heavy duty trucks. Records show GHG emissions are reduced by 5-10% when compared to diesel vehicles, which is not a large cut however it is still a step forward in reducing climate impact. Further reduction could be achieved by mixing liquefied methane from renewable resources with the fuel.

The process of making LNG includes liquefying natural gas to 600 times its original volume, making it practical for transport. The fuel is odourless, colourless, with no corrosive characteristics and does not present as toxic. The liquefying process, conducted in a liquefaction plant, separates the natural gas into: water, acid gases and heavy hydrocarbons. Main component within LNG is methane (between 85 - 95%) along with other components such as ethane, butane, propane and nitrogen. For ease of transport and to reduce its volume, the purified gas is cooled at -162 degrees Celsius, forming a liquid state. The fuel is then used as a fuel alternative. [20]

Advantages of LNG include the vapours ability to readily mix with air, proving much safer when used at refuelling stations. In addition it does not ignite, explode or burn. For use in heavy duty trucks its major benefit is low cost. [33] When compared to the price of diesel per km the LNG costs 0.306 USD/km whereas diesel is 0.444 USD/km, showing a 28% saving. However a LNG vehicle purchase is estimated to be 30-40% more expensive. Despite this, it still proves economically viable to make the transition to an LNG truck, as the payback period is much shorter.

Refuelling infrastructure is most significant in China with around 3,000 CNG/LNG filling stations. There is additional plans to increase this to around 12,000 by 2020. Whilst in Europe numbers are significantly lower (around 100 filling stations) with majority found in Northwest Europe (Norway, Netherlands and UK). Figure 7.1 highlights the current filling stations in Europe with proposed/in construction stations depicted in yellow.

Figure 7.1: Current and Proposed LNG Filling Stations in Europe. [20]

In addition to LNG, bioethanol is deemed as an attractive alternative fuel due to its renewable bio-based resource and its ability to produce less particulate emissions. Producing this reduction whilst operating in a compression-ignition engine, as the fuel is oxygenated. As a fuel source its adoption is mainly found in locations where agricultural products are readily available. [34] North America, South America and Central America are responsible for majority of bioethanol production; accounting for three-quarters of the world's total production. Within the current transportation sector bioethanol (and biodiesel) are stated to be ready in replacing gasoline and diesel fuel. Its economic, environmental, strategic and infrastructure impacts are deemed good.

The fuel is classified as an alcohol and it is made from raw materials such as: sugar beet, sugar cane, wheat, corn, ligneous plants or potatoes. To produce the fuel, saccharification, fermentation and stratified distillation (up to four levels) must be conducted. For fuel use is it then blended with either gasoline or diesel. In comparison to fossil fuels, it has the following qualities: a high octane number; the ability to reduce particle emissions that would endanger human health; similar properties to gasoline therefore does not require engine modifications for use; classified as a renewable fuels with no CO_2 emissions; low cost production; in its pure form it is soluble in all proportions with water alongside, ether, benzene, acetone and other organic solvents, and its chemical function is majority OH-group therefore can help reactions within the chemical industry such as ester formation, oxidation, dehydration and halogenation. [35]

The feedstock for bioethanol is classified into four main categories highlighted in Figure 7.2. First-generation feedstock is mainly edible food crops such as wheat, potato, sugarcane, barley etc. This generation receives criticism as there is debate over the feasibility of production when compared to land utilisation and food supply. Second generation is non-edible feedstock (or lignocellulosic biomass) such as woody biomass, forest residue, municipal solid waste and animal fat etc. This generation has prominent advantages over first-generation, as it has no direct competition with food crops and can grow on land conditions of poorer quality (i.e. no fertiliser or water). First generation however, contain higher sugar concentrations therefore produce more bioethanol. Third generation feedstock encompass algae biomass, which proves promising at low cost production. It also has a higher energy density alongside a higher conversion efficiency compared to first and second generation. Fourth generation feedstock remains in its early stages but considered to have potential negative carbon effect as the carbon produced by the technology is less than the carbon captured. [36]

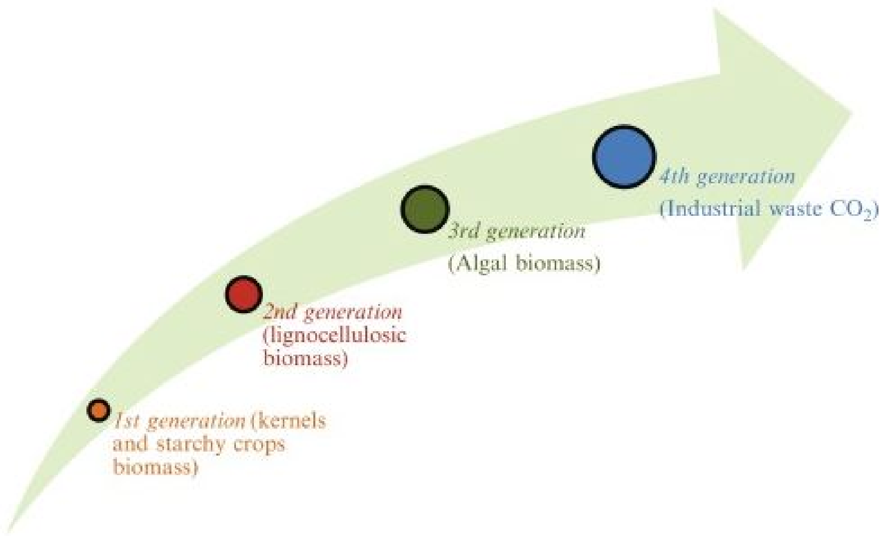

Figure 7.2: Bioethanol feedstock classification [36].

7.1.1 LNG Emissions

To calculate LNG fuel emissions, Equation 5.1 with the following specifications used:

Average LNG Fuel Consumption (l/km) = 0.25

LNG Lower Heating Value (MJ/l) = 48.6

LNG GHG Emissions (gCO_2e/MJ) = 211.7 [20]

Based on the original 2019 Grand Prix calendar the following results obtained:

Table 7.1: LNG Road Transport Emissions

Road Freight Journey	LNG WTW CO_2e (tonne) per truck
Spain - Monaco	1.77
France - Austria	2.91
Austria - UK	4.07
UK - Germany	1.5
Germany - Hungary	2.46
Hungary - Belgium	3.14
Belgium - Italy	1.97

Total CO_2e emissions for one truck fuelled by LNG would produce **17.82 tonnes**, showing a saving of 9% which coincides with literature.

7.1.2 Bioethanol Emissions

Bioethanol emissions calculated using the same method (Equation 5.1) with the following specifications below. As bioethanol can be produced from different raw materials, two were chosen as potential fuel feedstock. Firstly bioethanol from wheat grain and secondly bioethanol from sugar beet; both first generation. For both productions, natural gas-fired boilers and grid electricity used, and 100% bioethanol assumed.

Average Bioethanol Fuel Consumption (l/km) = 0.397 [37]

Bioethanol Lower Heating Value (MJ/l) = 26.8 [38]

Wheat Grain *Bioethanol GHG Emissions* (gCO_2e/MJ) *= 44*

Sugar Beet *Bioethanol GHG Emissions* (gCO_2e/MJ) *= 47* [39]

For bioethanol produced from wheat grain the following CO_2e emissions were calculated:

Table 7.2: Bioethanol (wheat grain) Road Transport Emissions

Road Freight Journey	**Bioethanol WTW CO_2e (tonne) per truck**
Spain - Monaco	0.32
France - Austria	0.53
Austria - UK	0.74
UK - Germany	0.27
Germany - Hungary	0.45
Hungary - Belgium	0.57
Belgium - Italy	0.36

For wheat grain the total CO_2e emissions being **3.24 tonnes**, producing an 83% emission saving over the original diesel powered truck.

Secondly, the CO_2e emissions produced from sugar beet bioethanol shown in Table 7.3:

Table 7.3: Bioethanol (sugarbeet) Road Transport Emissions

Road Freight Journey	**Bioethanol WTW CO_2e (tonne) per truck**
Spain - Monaco	0.34
France - Austria	0.57
Austria - UK	0.79
UK - Germany	0.29
Germany - Hungary	0.48
Hungary - Belgium	0.61
Belgium - Italy	0.38

For sugar beet the total CO_2e emissions being 3.46 tonnes, producing a 82% emission saving over the original diesel powered truck.

7.2 Sea Freight Biofuel

Electrification of shipping not an option as the technology is not yet established for the distances required, and again hydrogen for this sector proves costly. Several LNG ships were deployed in Australia however the issue of unburnt methane categorised LNG as a non alternative fuel option, therefore an unlikely long-term answer for the shipping industry. [24] Biofuels prove the most promising option however the generation of suitable biofuel proves challenging. DHL state in their alternative fuel paper that long-distance shipping excludes crop-based biofuel as the demand on land and agriculture is deemed too high. The primary requirements for any freight company are; an extensive filling station network, reasonable obtainment costs and smooth operation of infrastructure. The ultimate goal is to find equilibrium between the commercial viability, operational feasibility and environmental performance. [40]

One of the main contenders is methanol (methyl alcohol), with this reduced air emissions are experienced and there is no requirement to install an exhaust gas cleaning system. This is advantageous to ship owners as it provides a reasonable alternative fuel, allowing them to comply with increasingly stringent environmental regulations. The investigation into methanol as marine fuel began in 2006 with a number of projects following thereafter, some examples are shown in Figure 7.3. Methapu being the earliest project to date with a goal to investigate the use of a solid oxide fuel cell, with methanol providing electrical power for onboard essential services. A more recent project, SUMMETH, investigated concepts of methanol combustion for small marine engines and their compatibility for the marine market.

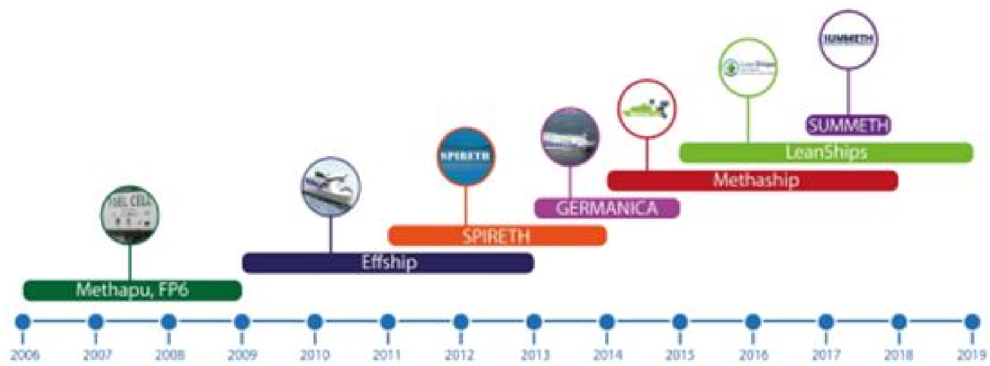

Figure 7.3: Timeline of projects investigating methanol as an alternative marine fuel.

Methanol can be produced from various feedstock such as wastes, second generation biomass, and even CO_2. It is classified as the simplest alcohol and used widely in the chemical industry with properties including; no colour, liquid physical state, no fuel treatment required onboard ship and flammability at ambient temperatures. An advantage to the fuel is its ability to fully dissolve in water, protecting any aquatic life if a spill or leak occurs. Compared to conventional fuels methanol experiences a lower energy density, proving slightly disadvantageous as extra storage is required, in addition corrosive tendencies occur. Safe handling guidelines state considerations such as type of equipment, process conditions, flow, temperature etc, all need to be considered when selecting the appropriate materials.

Major production of methanol originates in China, with United States following behind. Vast methanol production is located near feedstock with natural gas in use, the advantage here being, it is cheaper and more efficient to transport than the feedstock gas. An example plantation in Sweden produces renewable methanol from the gasification of black liquor (a by-product of paper mills and pulp). An Icelandic firm, Carbon Recycling International, is also producing renewably certified methanol fuel by using energy and CO_2 emissions from a geothermal plant.

For methanol distribution, it is a widely used alcohol in the chemical industry therefore sufficient storage and distribution infrastructure is already established, especially in Europe. At shipping ports additional storage facilities will be required for fuel, if not already available however tank requirements are similar to gasoline, ethanol and petroleum distillates, so the technology is already established. The average fuel price for methanol is $412 per tonne and when compared to conventional maritime fuel this proves attractive as it is cheaper and has a shorter payback period. Methanol has the capacity to be competitive with other fuels. [41]

Alternatively, ammonia has been proposed an another advantageous marine fuel replacement. The carbon free molecule produced from nitrogen and hydrogen, if made from renewable sources, has the ability to be CO_2 emission free. Currently the fuel is made from fossil fuel based hydrogen however renewable ammonia is under development and hoping to be a viable option soon. The fuel, as an energy carrier, has the ability to be used within internal combustion engines or fuel cells if existing technologies are modified slightly. But for marine use, no ammonia powered propulsion technologies have been commercialised yet. Initiatives such as MAN Energy solutions are amongst one of the organizations hoping to achieve this; they developed a dual-fuel engine for liquefied petroleum gas (LPG) use, yet claim it can adopt liquid ammonia in a dual fuel setup. Together with the American Bureau of Shipping (ABS) and Shanghai Merchant Ship Design and Research Institute (SDARI), MAN Energy solutions developed a project for a container vessel to utilise ammonia fuel within the dual-fuel engine. ShipFC is another project funded by Europe, trying to convert an offshore vessel to run on an ammonia fuel cell.

Ammonia proves toxic, especially at high concentrations if released into the atmosphere can prove seriously health threatening. If a leak occurs in water, it converts ammonia into ammonia ions, also proving toxic for living organisms with potential long term effects. Released into the air it evaporates upwards due to its low density dilute; but how fast and to what extent relies on several factors. Marine structures would also need to be designed accordingly as ammonia is also highly corrosive. Alongside this, it has the ability to create explosive mixtures if mixed with hydrogen from cracked ammonia and air. Therefore if to be used as a future marine fuel many technological developments are required.

To store the fuel large insulated pressurised tanks are required, since ammonia is more energy dense compared to compressed hydrogen and liquid hydrogen. Unlike liquefied hydrogen however, there is no need for cryogenic storage. With bunkering or fuel infrastructure no main issues arise, only requirement is a well-functioning bunkering system and fuel infrastructure. [43] Even though the fuel appears disadvantageous compared to the development of other alternative marine fuels, ammonia does provide the following advantages: unlike hydrogen the fuel already has existing global logistics infrastructure; as stated it does not require a cryogenic storage facility; its risk profile can be managed alongside existing standards and procedures; it does not require complicated onboard processing within internal combustion engines or fuel cells making it flexible; and finally it provides sufficient energy storage for ships lasting long periods of time due to it being relatively energy dense as a liquid. [44]

The fuels ability to emit zero CO_2 emissions when combusted is ammonia's main attraction, here carbon capture and biomass-based fuels are not required. Even if carbon sourced ammonia is produced, carbon capture is less complicated at production stages in factories, than onboard a ship. [45] Figure 7.4 below indicates the process in detail of producing a carbon neutral fuel, example here being ammonia and methanol:

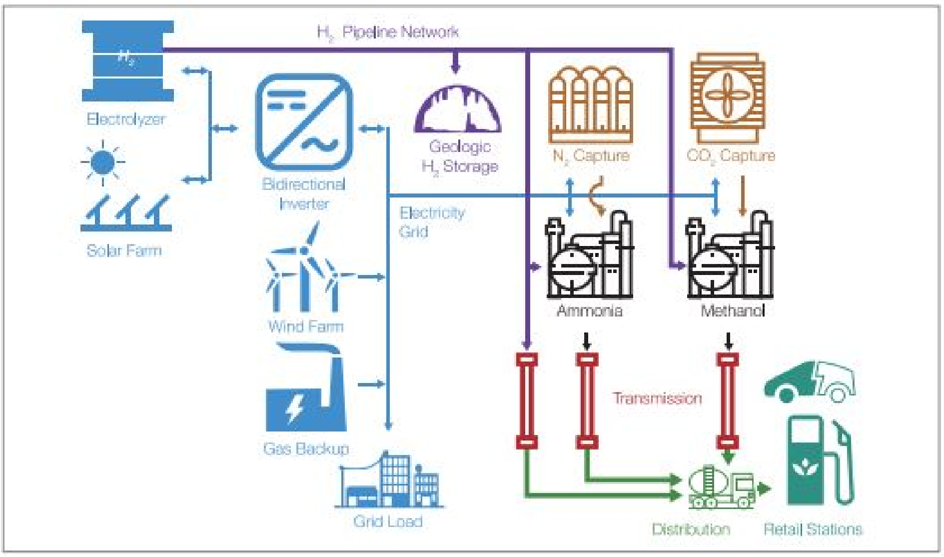

Figure 7.4: Production of Carbon Neutral Fuel [46]

In order to be used as a marine fuel the production of renewable ammonia needs to increase substantially. With the large-scale production being from renewable based electricity; here subdued physical restrictions are experienced compared to some biofuel. Current prices, in relation to energy content of ammonia, prove substantially higher when compared to LNG or marine gasoil (MGO). However the future of marine fuels will not be dominated by one alternative fuel in particular, combinations will be favoured therefore even though ammonia currently proves far-fetched its not to say future developments cannot make it a favourable marine fuel alternative. [43]

7.2.1 Methanol Emissions

DHL's online carbon calculator did not feature alternative fuel options therefore could not be used to calculate CO_2e generated from methanol. With vast majority of freight transport options outsourced the energy/fuel consumption data is not readily available, so emission calculations prove difficult. Depending on the feedstock CO_2e emissions differ, for natural gas it is stated in literature to reduce CO_2e emissions by %, with biomass feedstock-based methanol discountable as they are biogenic. [42] Using Table 5.5 generated by DHL's carbon calculator, a 25% reduction is applied to highlight methanol's theoretical CO_2e reducing potential.

Table 7.4: Methanol Ship Emission

Sea Freight Journey	**Methanol WTW CO_2e (tonne)**
UK - Australia	100.91
Australia - Bahrain	70.32
Bahrain - China	37.51
China - Azerbaijan	63.48
Azerbaijan - Spain	43.78
Monaco - Canada	36.88
Canada - France	35.78
Italy - Singapore	38.27
Singapore - Russia	41.06
Russia - Japan	59.51
Japan - Mexico	74.63
Mexico - USA	23.49
USA - Brazil	56.26
Brazil - Abu Dhabi	86.65

Using methanol as a marine fuel emits total CO_2e of **769 tonnes**. This, as previously stated, is an estimated value as the fuel consumption of specific ships is not readily available. With the fuel and alternate route implemented, theoretical CO_2e savings of 58% are experienced.

7.2.2 Ammonia Emissions

The CO_2e percentage reduction of ammonia based fuel can range from 0-100%, depending on the process of fuel production. With renewable energy generation, ammonia would produce zero carbon emissions, eliminating F1's maritime emissions completely. When running an ammonia-diesel fuel engine (project by MAN Energy solutions) on larger ships, carbon emissions can be reduced by 40%, mixing the existing MGO and ammonia in a 4:6 ratio. With a ratio of 1:9, 80% reductions potentially achieved. [46] Each individual journey would produce the following theoretical emissions shown in Table 7.5 for both percentages.

Table 7.5: Ammonia Ship Emission

Sea Freight Journey	40%	80%
UK - Australia	80.73	26.91
Australia - Bahrain	56.26	18.75
Bahrain - China	30.01	10.00
China - Azerbaijan	50.78	16.93
Azerbaijan - Spain	35.02	11.67
Monaco - Canada	29.50	9.83
Canada - France	28.62	9.64
Italy - Singapore	30.62	10.21
Singapore - Russia	32.85	10.95
Russia - Japan	47.61	15.87
Japan - Mexico	59.70	19.90
Mexico - USA	18.79	6.26
USA - Brazil	45.01	15.00
Brazil - Abu Dhabi	69.32	23.11

Total theoretical CO_2e emissions for the 40% and 80% saving are **615 tonne** and **205 tonnes** respectively. This would prove extremely advantageous for the marine sector if ammonia were to become commercially viable.

7.3 Air freight Biofuel

Similar to shipping, electrification for long range aviation is not an option, extensive research and development mainly focuses on its applicability in short range journeys with many challenges still faced. The aviation sectors development of biofuel proves the most advantageous route in reducing emissions. But DHL state in their alternative fuel paper that kerosene, the current aviation fuel, will not be eliminated any time soon; especially for long-haul flights as biofuel still faces extensive development. The forefront of aviations future lies in sustainable synthetic fuels; such as synthetic kerosene. By using these fuels exclusively, Europe is currently unable to match fuel demands due to its lack of bio-refineries. Economic viability also plays a key role in the production of sustainable aviation as current costs show magnitudes three to four times higher, producing synthetic fuels compared to conventional aviation fuel. With fuel accounting for one-third of an airlines operating costs, if biofuel aims to be competitive in the current market, these costs need to reduce. Industry, research organisations, alongside political communities have joined forces to tackle biofuel, but there has been no succession in meeting the demands required at a reasonable price. An example being aireg e.V. who are a German non-governmental organisation (NGO) researching the applicability of sustainable aviation fuels, with DHL being one of their charter members. [40] Airlines including KLM, Air New Zealand, Alaska Airlines, Quantas and Virgin Australia are amongst an excess of fifty airlines operating test flights using different blends and types of biofuel. Different aircraft, both revenue and non-revenue services, adopted these fuels with testing showing no degrade or loss of engine performance. If the aviation sectors hopes to attain their emission target of 50% CO_2 reduction by 2050, the sector believes biofuel is the primary strategy going forward. [47]

Most common biofuel under investigation is biokerosene, also known as biojet, produced from various feedstock including vegetable and animal fat. Studies suggests the fuel can reduce GHG emissions by 50-95% depending on the biofuel feedstock. With high production costs the fuel implementation has been limited; even though commercial scale production is technically feasible. An advantage of the fuel being, no modification required of the aircraft airframe, engine or refuelling structure. [40]

SPK an example of bio-kerosene, is produced from hydroprocessed esters and fatty acids (HEFA), with this being the most mature alternative fuel pathway. The process entails the hydroprocessing of vegetable oils and animal fats, with an additional isomerisation stage to lower the fuels freezing point. Hydrogen is used to change compounds such as aromatics and alkenes into cycloalkanes and paraffin's, which are less reactive and more stable. The process for hydrotreated vegetable oil (HVO) is the same minus the isomerisation stage. In comparison to other alternative fuel routes HEFA is simple and more mature, making it the only alternative fuel in commercial use. Production cost of HVO is dependent on the deployment stage and plant size, it can range from £1000 to £1225 per tonne. For an upgrade to HEFA, a relatively small cost is associated for the extra isomerisation equipment.

The main limitation to the process is the availability of feedstock; vegetable oil for example is constrained by sustainability concerns and land availability. HEFA plants can also consider feedstock such as fermented sugar therefore there are other options available. The current commercial aviation fuel demand, for both domestic and international flights, is averaged at 280 million tonne per year. The HEFA production capacity at a global scale, from refineries dedicated to hydro-processing and co-processing, is around 5 million tonne per year. Therefore if HEFA is to become a viable alternative for the aviation industry, policies must be implemented to speed up the production. [48]

Second generation feedstock for bio-SPK include plant based oils such as camelina oil, jatropha oil, algae oils and waste cooking oils. These do not compete with food crops for arable land. For example, jatropha can be grown year round with optimum climate conditions for cultivation being in a tropical savannah; monsoon seasons alongside hot summers without any dry seasons. Production is therefore focused in countries such as Africa, South America and Asia. For a jatropha plantation, 25 years is the assumed lifespan after planting, with nutrients required to secure an optimum yield output. The nuts contain around 27-40% oil which is extracted from the seed, with a 35% assumption made for average oil content generated. For large scale production, required for aviation fuel use, jatropha oil is produced at a commercial oil mill instead of a farm producing small scale equivalents; this reduces the GHG emissions. However commercial cultivation and processing of this feedstock is still in early development stages. [49]

Like road transportation, bioethanol has also been an aviation biofuel contender with Brazil being a major producer in the market alongside the USA. With land significantly expanded in the last three decades, brazil produces yields of sugarcane specifically for bioethanol production. The interest of ethanol as an aviation fuel sparked as it has a known molecular formula and a predictable behaviour, regardless of the raw material used in synthesis or the application process. As stated in road transport application, it is obtained from the conversion of cellulosic biomass, alongside conventional sources presenting high feasibility and low cost. Smaller aircraft in brazil have operated on pure ethanol for many years, as its cultivation is focused on supplying single engine airplanes. Criticism of the fuels development and research is associated with the water consumption; required for both industrial processing and sugar cane production. However implementation of water reuse and efficient treatment systems are reducing this demand.

Switching from conventional aviation fuel to bioethanol provides major savings in operation cost and environmental impact. [50] Alcohol to jet fuel undergoes two separate processes; firstly the production of the alcohol usually by microbial fermentation of carbohydrates from biomass, and secondly the chemical conversion of the alcohols into hydrocarbons (i.e. jet fuel or diesel). Conversion of the alcohol into liquid hydrocarbon fuel begins with dehydration to yield the corresponding alkanes, then it is oligomerized to the chain length desired. Finally hydrogenation is undertaken to yield saturated hydrocarbons, used for blendstock in jet fuel production. A technical overview of the alcohol to jet process for production of bioethanol to biojet fuel is shown in Figure 7.5 below. Substantial progress in recent years has been achieved after alcohol to jet fuels were approved by the American Society for Testing and Materials (ASTM), with an initial maximum blending ratio of 30% increased to 50% including ethanol as a starting material. [51]

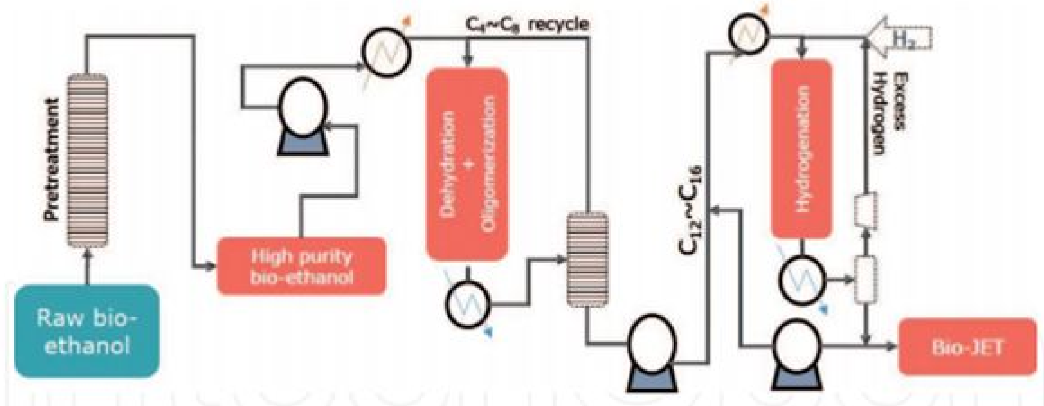

Figure 7.5: Technical overview of bioethanol to bio-jet production [52].

Companies such as Gevo and Vertimass, amongst some of the few majorly trying to upgrade bioethanol feasibility, are producing alcohol derived hydrocarbon fuels. Commercialization capability however has still not been accomplished. As always, economic feasibility is bio-jet fuels main hindrance. To understand its economic viability, a thorough assessment of the commercial production facility, upgrading process and distribution of the product are main considerations, these however require intensive process upgrades which are still in development stages. [52] If F1 were to implement bioethanol within their road transportation then it would be of high interest to try implement within other logistic sectors such as aircraft freight, as production can be for both sectors. Aviation is another transport sector that will not rely solely on one alternative fuel, various alternative usage will drive the sectors reduced greenhouse gas emissions.

7.3.1 Jatropha SPK Aircraft Emissions

It is recorded that jatropha-SPK results in 37% WTW CO_2e savings therefore this saving applied to the EF's in Table 5.3 (Section 5.1.3) generates the new EF's below: [53]

Table 7.6: Jatropha-SPK EF for Air Freight

Aircraft Range	**Distance Range (km)**	**Aircraft Type**	**WTW CO_2e (kg/tkm)**
Regional	< 785	Freight	1.32
Continental	785 – 3,600	Freight	0.58
Intercontinental	$> 3,600$	Freight	0.37

Using Equation 5.5 alongside new EF's in Table 7.6, the following CO_2e emissions were calculated jatropha-SPK:

Table 7.7: CO_2e Emission for Air Transport using Jatropha-SPK Fuel

Air Freight Journey	**WTW CO_2e (tonne)**
UK - Australia	6,628
Australia - Bahrain	4,755
Bahrain - China	2,705
China - Azerbaijan	2,522
Azerbaijan - Spain	1,585
Monaco - Canada	2,430
Canada - France	2,378
Italy - Singapore	4,040
Singapore - Russia	3,093
Russia - Japan	3,214
Japan - Mexico	4,551
Mexico - USA	781
USA - Brazil	3,191
Brazil - Abu Dhabi	4,772
Abu Dhabi - UK	2,215

Theoretically jatropha SPK, would reduce F1's air transport to **48,771 tonnes** of CO_2e.

7.3.2 Ethanol Aircraft Emissions

Ethanol (100%) fuel is recorded to produce 1513.2 kgCO_2e/tonne therefore new EF's were calculated based on Network for Transport Measures distances for each range (i.e. regional, continental and intercontinental). [54]

Table 7.8: Bioethanol EF for Air Freight

Aircraft Range	**Distance Range (km)**	**Aircraft Type**	**WTW CO_2e (kg/tkm)**
Regional	< 785	Freight	3.27
Continental	785 – 3,600	Freight	1.37
Intercontinental	$> 3,600$	Freight	0.23

Using Equation 5.5 and the new EF's in Table 7.8, the following CO_2e emissions were calculated for ethanol:

Table 7.9: CO_2e Emission for Air Transport using 100% Bioethanol Fuel

Air Freight Journey	WTW CO_2e (tonne)
UK - Australia	4,234
Australia - Bahrain	3,038
Bahrain - China	1,728
China - Azerbaijan	1,612
Azerbaijan - Spain	1,013
Monaco - Canada	1,552
Canada - France	1,519
Italy - Singapore	2,581
Singapore - Russia	1,976
Russia - Japan	1,996
Japan - Mexico	2,907
Mexico - USA	1,841
USA - Brazil	2,0.9
Brazil - Abu Dhabi	3,049
Abu Dhabi - UK	1,416

The implementation of 100% ethanol fuel would reduce F1's emissions by 58%, producing a total **32,500 tonnes** within the season.

7.4 Discussion

By implementing LNG and bioethanol alternative fuels within road transportation, CO_2e savings of 9% and 83% are experienced respectively. The LNG calculated result coincides with literature, stating emissions reductions are between 5-10%, this reduction does not proves significantly impactful however with the fast the pay off period, it could be an intermediate carbon reduction step for F1. In addition, the infrastructure is already established with more refuelling stations in construction, therefore for European Grand Prix races ,where the majority of road transporters are utilised, are secure with LNG fuel supply. Bioethanol adoption shows significant CO_2e reduction with wheat grain feedstock reducing by 83% and sugar beet by 82%. Both are first generation feedstock therefore there is growing concern over the production overtaking food crop cultivation and destroying arable land. But with bioethanol's feedstock flexibility, second and third generation can be used taking the pressure off first generation crop cultivation. The F1 hybrid cars already utilise 5% biofuel with plant to mix 10% by 2021; specifically an advanced sustainable ethanol. [61] Therefore if the motorsport is already cultivating bioethanol for car fuel it is in their best interest to broaden the use to other sectors such as road logistics. By road transporters combusting emissions whilst using bioethanol, this can be recaptured and used in photosynthesis of growing the new feedstock, keeping their emissions within a containment loop. Large scale production of bioethanol feedstock also reduces emissions as crop transportation is minimum with plantation close. Bioethanol proves attractive with numerous feedstock available and the potential large scale use within F1. If the alternative calendar utilised biofuel, the same CO_2e saving of 9% is encounter, compared to the original calendar, since road transport is utilised more.

For sea freight with the limited data available the emissions are theoretical; methanol use producing 769 tonnes and ammonia producing 615 tonnes or 205 tonnes depending on the fuel mix ratio. The maritime sector proves challenging in terms of sustainability, the majority of development and research has focused on smaller boats rather than large freight carriers therefore case studies prove difficult to attain. Theoretically if methanol and green ammonia were available, they would be extremely advantageous to reducing ships emissions. However modifications onboard are required; for methanol extra storage facilities due to its low energy density and for ammonia the ship materials need to be revised as ammonia is corrosive. Refuelling infrastructure is also poor therefore if the sector hopes to attain sustainability more policies and subsidies are required for research and testing to be conducted. Again maritime emissions are less intensive than road transportation therefore if sustainable practices were to be used, such as slow steaming or engine improvements to reduce fuel consumption, then carbon mitigation strategies could be adopted to recapture the additional emissions. Upgrading of ships may be the quick fix for the time being until alternative fuels become commercialised.

Both biofuel present advantageous to the aviation sector and F1, with jatropha-SPK theoretically reducing emissions by 37% and bioethanol by 58%. Both would not require aircraft adaptations and can be introduced smoothly, but again issues arise regarding feedstock cultivation and land availability. Commercialisation of both fuels still requires development to meet the aircraft sectors fuel demands, however with various 'drop-in' fuels available the sector can utilise more than one, providing extra security. Jatropha-SPK is a second generation feedstock therefore it can grow on poorer land conditions, reducing investment costs, as fertilisers are not required. Also HEFA is the most mature alternative fuel pathway, so production of jatropha-SPK is further developed in comparison to other alternative 'drop-in' fuels. Bioethanol proves hopeful with the USA and Brazil producing copious amounts and Brazil also running their small planes on 100% ethanol fuel. Alongside this, as mentioned with bioethanol in road transportation, if F1 focuses on adopting this fuel across the board then the combustion and production is within a containment loop, no new emissions are generated. It would be within F1's best interest to invest considering they plan to adopt it in their race cars, its flexibility within the motorsport is economically and environmentally beneficial.

The major limitation to 'drop-in' fuels is economic viability, the cost is much greater than kerosene therefore aircraft operators and airlines have no interest using them, since fuel costs dominate a third of an airlines operating costs. If any major breakthroughs are to be witnessed within this sector, policies need to be implemented and fuel costs need to be reduced. The government needs to provide resources for further research and development, allowing production costs to reduce influencing operators to use the fuel. At the minute the sector has voluntary sustainability strategies, with engineers and manufacturers improving fuel efficiency, aircraft aerodynamics, and aircraft operations which reduce CO_2e emissions majorly. But these need to be enforced by governmental action plans, ensuring equal treatment to aircraft across the sector. The ASTM approving 50% fuel blend is a major step forward for, but fuel security is not yet established to meet demands. Future prospects look hopeful for the sector but for alternative fuels to be considered, many improvements are still required regarding, refuelling infrastructure, blend ratios, fuel production and availability.

Chapter 8

Evaluation of Robustness

Robustness assessment was carried out and researched alongside alternative calculations undertaken on selected logistics. Initially road transport emission were analysed and calculations based on a different method. For freight transport operations the vast majority of data is outsourced, therefore fuel consumption or energy data is difficult to obtain. In this absence, CO_2e emissions calculated using an activity-based method shown below in Equation 8.1. [55] Without knowledge of the transporter type or number of transporters, it is assumed the truck type is a rigid truck with typical capacity of 15 tonnes. F1 road transport is only utilised in Europe and literature states the European WTW EF is 0.130 kg/tkm. These factors were applied to the equation below to calculate the CO_2e emissions [27]

$$CO_2e(tonnes) = \frac{W.d.EF}{1000} \tag{8.1}$$

where:

W = Freight Weight (kg)

d = Distance (km)

EF = Average CO_2e Emission Factor per tonne-km ($kgCO_2$/tkm)

Table 8.1 below provides a comparison between original CO_2e emissions calculated and emissions from Equation 5.1.

Table 8.1: Road Freight CO_2e Emission Comparison

Road Freight Journey	**Original WTW CO_2e (tonne) per truck**	**Alternative WTW CO_2e (tonne) per truck**
Spain - Monaco	1.94	1.34
France - Austria	3.20	2.20
Austria - UK	4.47	3.08
UK - Germany	1.64	1.13
Germany - Hungary	2.70	1.86
Hungary - Belgium	3.45	2.38
Belgium - Italy	2.16	1.49

The alternative calculations method produced emissions 31% greater than original, with the estimation approach calculation results are not going to be as accurate as having the data readily available. With specific number of transporters used by F1, the type, plus cargo load available, more accurate results are obtainable.

The sea freight emissions generated by DHL's carbon calculator were compared to alternative emission calculations to determine the strength of DHL's recorded CO_2e values. [56] Again with limited data available, the activity-based calculation method was applied. For a diesel fuelled cargo ship literature states a WTW EF of 0.20 $kgCO_2/tkm$, which is applied to Equation 8.1 alongside 500 tonnes of cargo weight and distances from Table 5.5. [55] The calculated results in comparison to DHL's carbon calculator are shown in Table 8.2.

Table 8.2: Sea Freight CO_2e Emission Comparison

Sea Freight Journey	**DHL's Stated WTW CO_2e (tonne)**	**Calculated WTW CO_2e (tonne)**
UK - Australia	134.55	239.55
Australia - Bahrain	93.76	148.44
Bahrain - China	50.02	126.53
China - Azerbaijan	84.64	193.93
Azerbaijan - Spain	58.37	54.59
Monaco - Canada	49.17	90.42
Canada - France	47.70	92.44
Italy - Singapore	51.03	143.09
Singapore - Russia	54.74	141.85
Russia - Japan	79.35	204.42
Japan - Mexico	99.50	224.17
Mexico - USA	31.32	21.93
USA - Brazil	75.02	127.42
Brazil - Abu Dhabi	115.53	181.71

The alternative calculations show a 49% increase compared to DHL's stated emissions, therefore it is uncertain how accurate the emissions stated per journey are. The activity-based calculation is an estimation, due to the absence of data, therefore DHL's calculated emissions have the potential to be of greater accuracy. The company identifies the type of vessel required and fuel consumption associated with each journey, in addition to the precise sea route taken by their vessel, with specific EF's dependant on each region travelled in. Therefore with more data readily available, the DHL stated emissions provide greater accuracy than the activity-based estimation. It would be beneficial if DHL released the data used within the calculator to understand its produced emission value.

For air freight, alternative calculations were undertaken using the following Equation 8.2 below. The Department for Environment, Food and Rural Affairs (DEFRA) produced EF's for various airfreight; EF of 0.606 $kgCO_2e/tkm$ for aircraft travelling distances over 3,700 km and 1.316 $kgCO_2e/tkm$ for any distance below. Alongside an uplift factor of 109%. [57] By maintaining the transportation cargo of 660 tonnes and flight distances found in Table 5.6, alternative CO_2e emissions were calculated.

$$CO_2e(kg) = \frac{T.EF.UF}{1000} \tag{8.2}$$

where:

T = Tonne-km Travelled (tkm)

EF = Emission Factor (kgCO_2e/tkm)

UF = Distance Uplift Factor (%)

The new results compared to the original air freight emissions are highlighted in Table 8.3 below.

Table 8.3: Air Freight CO_2e Emission Comparison

Air Freight Journey	**Original WTW CO_2e (tonne)**	**Alternative WTW CO_2e (tonne)**
UK - Australia	10,520	11,981
Australia - Bahrain	7,547	8,595
Bahrain - China	4,293	4,889
China - Azerbaijan	4,034	4,560
Azerbaijan - Spain	2,517	2,866
Monaco - Canada	3,857	4,392
Canada - France	3,774	4,298
Italy - Singapore	6,413	7,304
Singapore - Russia	4,910	5,591
Russia - Japan	4,959	5,648
Japan - Mexico	7,223	8,226
Mexico - USA	1,240	1,933
USA - Brazil	5,065	5,768
Brazil - Abu Dhabi	7,575	8,627
Abu Dhabi - UK	3,517	4,005

Results shows a 14% increase of emissions when compared to the original calculation results, this is due to the difference in EF's and the alternative methods use of an uplift factor. The difference does not prove concerning and ascertains the CO_2e emissions calculated for air freight are plausible.

Emissions generated by biofuel appear harder to confirm, especially in maritime freight, as extensive research has not been undertaken. For road transport, LNG states to reduce emissions by 5-10% and therefore the results in Section 7.1.1 prove promising as a 9% CO_2e reduction was achieved. [20] For bioethanol adoption within road transport, various case studies of trucks utilising the fuel were analysed. For example Scania, one of the world's leading heavy-duty vehicle manufacturer, partnered with Clariant, a world pioneer in speciality chemicals whom produce sustainable cellulosic ethanol from feedstock such as wheat straw and sugarcane, reported CO_2e reduction of 90% when compared to the diesel truck fleet. [58] Another company Novozymes, responsible for the world's first commercial scale lignocellulosic ethanol facility in Italy, report adoption of 95% blend bioethanol in heavy duty trucks can reduce CO_2e emissions also by 90%. Therefore CO_2e savings of 83% from wheat grain and 82% from sugar beet, calculated in Section 7.1.2 are highly feasible. [59]

Biofuel adoption within the marine sector mainly investigated in smaller ships therefore extensive research is still being conducted for integration in larger vessels. Due to this, case studies prove difficult to obtain in order to verify results. The project SUMMETH reported reduced life cycle emission between 75 and 90% however again this was adopted in smaller ships. [60] Currently methanol used in marine engines is undergoing trials; there are no life cycle assessments evaluating the use in larger ships. Therefore, results in Section 7.2.1 are theoretical as data is not available, the CO_2e reduction unlike to be achieved in near future if fuel adopted. The same applies for Ammonia.

In 2010, Airbus together with TAM Airlines conducted the first jatropha based biofuel flight. The Airbus A320 flew over Latin America with a 50% fuel blend of locally sourced Brazilian jatropha-SPK and kerosene. Airbus state their studies show a carbon reduction of 80% is experienced whilst using biofuel made form Jatropha. [63] Alongside this airline such as Air New Zealand and Air China have adopted jatropha-SPK blended jet fuel, with Air New Zealand flying a Boeing 747 aircraft using 50-50 blend without any engine modifications. The flight was recorded a success, however concluded several years of testing is required before certification of the fuel is secure. Air New Zealand never released any information regarding carbon saving. [64] Results from Section 7.3.1 have the potential to be reduced further, if a higher CO_2e reduction similar to Airbus stated emission savings was implemented. For bioethanol adoption, Alaska Airlines are one of the airlines at the forefront of its use. The airline partnered with sustainable fuel supplier Gevo in 2016 with a 20% fuel blend used in flight, made from sustainable U.S corn. Alaska Airlines trialled the fuel in two flight stating their GHG emissions were reduced by around 50%. [62] The specifications of the flight were not published therefore the GHG savings stated by the airline are deemed as an estimation. With results in Section 7.3.2 showing 58% CO_2e saving, the statement from Alaska Airlines highlights bioethanol's potential feasibility.

Chapter 9

Conclusion

In conclusion, F1 largest CO2e emitting sector is logistics. This research investigated the current logistic emissions for road, sea and air freight, in addition to new emissions generated by an alternative Grand Prix seasonal calendar. Finally various biofuel options were analysed for road, sea and air transport with various case studies examined, securing the feasibility of biofuel emission reduction. For F1 to drastically reduce their carbon footprint this sector should be at the forefront of their sustainable practice adoption. The analysis highlights major emission reduction by implementing an efficient Grand Prix Seasonal calendar; ensuring maximum use of road transportation during European races alongside road transport adoption between, Bahrain, Azerbaijan and Abu Dhabi. This quick and simple fix can reduce logistic CO2e emissions by 44%, since sea and air transport is reduced and freight travelling progressively across the globe instead of back and forth. Climate conditions were factored into the new calendar schedule and the new layout is believed to be the optimum timetable with minimum chance of race cancellation. Additional night time races will also ensure this. For F1 to show quick sustainable practice, this alternative calendar should be at the forefront of the sports changes.

Additionally biofuel adoption within freight transportation was evaluated, with road transport most likely to implement its use in the near future. Greater research and development is highlighted within the road transport sector, with refuelling infrastructure well advanced compared to sea and air alongside certification of various biofuel. For sea vessels the majority of biofuel research is conducted on smaller ships therefore extensive testing and development is required on larger vessels before certification is granted. In addition refuelling infrastructure is limited, with some biofuel even proving corrosive; therefore material upgrade on ship is required. Aviation biofuel has been under serious investigation however no biofuel is yet able to meet airline demands. Economic viability is also crucial if airlines are to consider using it, as current costs prove higher than conventional kerosene. Within the near future biofuel does not appear feasible for large aircraft or vessels, therefore advancements in engine efficiency and materials might be the optimum solution to reduce their emissions. Biofuel in the short term should be highly adopted by the road transport sector, as it proves environmentally and economically viable. The race cars currently using bioethanol therefore if this was to be mirrored as their road freight fuel, production generates no new emissions, a containment loop is created and emissions help the growth of the biofuel feedstock.

F1 acknowledge the need for change within the sport, given the current global climate crisis and with their wealth of sponsors and engineers their innovation and influence, could pioneer sustainable practice globally. Logistics is one sector considered within this paper, however event operations, business travel and the factories/facilities all play a crucial role in reducing F1's overall carbon footprint.

Bibliography

[1] M. Jenkins and S. Floyd. (2001) 'Trajectories in the Evolution of Technology: A Multi-Level Study of Competition in Formula 1 Racing', *Organization Studies*, 22(6), pp. 945-969. doi:10.1177/0170840601226003.

[2] Liberty Media (2019). *F1 Fact Sheet.*
Available at: http://libertymedia.com/pdfs/Formula%201%20Fact%20Sheet %20Jan%202020.pdf. [Accessed 16 Aug. 2020].

[3] Papachristos, G. (2014). Technology, performance and team adaptation to regulation in Formula 1. *In 32nd International Conference of the System Dynamics Society, Delft, The Netherlands, 20-24 July 2014; Authors version.*

[4] Formula 1® (2019). *Formula 1 announces plan to be Net Zero Carbon by 2030.* [online] Formula1.com. Available at: https://www.formula1.com/en/latest/article.formula-1-announces-plan-to-be-net-zero-carbon-by-2030.5IaX2AZHyy7jqxl6wra6CZ.html [Accessed 16 Aug. 2020].

[5] Thomas, D. (2020). Can Formula 1 really go "carbon neutral" by 2030? *BBC News.* [online] 24 Jan. Available at: https://www.bbc.co.uk/news/business-51226066 [Accessed 16 Aug. 2020].

[6] Dingle, Greg. (2009). Sustaining the race: A review of literature pertaining to the environmental sustainability of motorsport. International Journal of Sports Marketing and Sponsorship. 11. 80-96. 10.1108/IJSMS-11-01-2009-B006.

[7] 2020 International Sporting Code - 2020 (ENG/FRA - clean version) 24.04.2020 Published on 24.04.20

[8] Boretti, A. (2019). Energy flow of a 2018 FIA F1 racing car and proposed changes to the powertrain rules. *Nonlinear Engineering*, 9(1), pp.28-34.

[9] Boretti, A. (2019). Energy flow of a 2018 FIA F1 racing car and proposed changes to the powertrain rules. *Nonlinear Engineering*, [online] 9(1), pp.28–34.
Available at:
https://www.degruyter.com/view/journals/nleng/9/1/article-p28.xml?language=en
[Accessed 18 August 2020].

[10] STEPIEN, Z., (2016). A new generation of F1 race engines – hybrid power units. *Combustion Engines*. 167(4), pp.22-37. doi:10.19206/CE-2016-403

[11] Woisetschlager, D.M., 2007. Team-sponsorship in the Formula One–does it affect brand perception? An empirical assessment in the German car market. *ACR North American Advances*. pp. 616-623.

[12] Sylt, C. (2019). Revealed: Sponsors Fuel Formula One With $30 Billion. *Forbes*. [online] 19 May.
Available at :https://www.forbes.com/sites/csylt/2019/05/19/revealed-sponsors-fuel-formula-one-with-30-billion/#513922724161 [Accessed 16 Aug. 2020].

[13] Richards, G. (2019). F1 aims to set benchmark for sporting world with pledge to go carbon neutral. *The Guardian*. [online] 12 Nov.
Available at: https://www.theguardian.com/sport/2019/nov/12/f1-reveals-plans-for-net-zero-carbon-footprint-and-sustainable-products#img-1 [Accessed 16 Aug. 2020].

[14] Formula 1® (2019). *Sustainability Strategy*. [online] Formula 1.com.

Available at: https://corp.formula1.com/wp-content/uploads/2019/11/Environmental-sustainability-Corp-website-vFINAL.pdf [Accessed 16 Aug. 2020].

[15] *Jenkins, M., Pasternak, K. and West, R., (2016). Performance at the Limit: Business Lessons from Formula 1® Motor Racing.* Cambridge University Press.

[16] DHL (2018). *Formula 1® Logistics: Key Stats. DHL.com.* Available at: https://www.dhl.com/content/dam/dhl/global/core/documents/info-graphics/glo-infografik-formula1.jpg [Accessed 16 Aug. 2020].

[17] Race Fans (2018). *2019 F1 calendar*. [online] racefans.net. Available at: https://www.racefans.net/2019-f1-season/2019-f1-calendar/ [Accessed 16 Aug. 2020].

[18] Iyengar, R., (2017). *The Logistics Behind F1.* [online] Medium. Available at: https://medium.com/speedbox-is-typing/the-logistics-behind-f1-7537e445de20 [Accessed 6 July 2020].

[19] Aston Martin Red Bull Racing, (2015). *Twitter*. [online] Twitter.com. Available at: https://twitter.com/redbullracing/status/589116159854780416?s=20 [Accessed 6 July 2020].

[20] Smajla, I., Karasalihović Sedlar, D., Drljača, B. and Jukić, L. (2019). Fuel Switch to LNG in Heavy Truck Traffic. *Energies*, 12(3), p.515.

[21] DHL (2016). *CARBON CALCULATOR: KNOW YOUR FOOTPRINT*. dhl.com. Available at: https://www.dhl.com/content/dam/dhl/global/core/documents/pdf/gogreen/dhl-gogreen-carbon-calculator-062016.pdf [Accessed 16 Aug. 2020].

[22] DHL (n.d.). *Carbon Calculator*. [online] www.dhl-carboncalculator.com.
Available at: https://www.dhl-carboncalculator.com/#/scenarios [Accessed 16 Aug. 2020].

[23] Osorio-Tejada, J.L., Llera-Sastresa, E. and Scarpellini, S., (2017). Liquefied natural gas: Could it be a reliable option for road freight transport in the EU?. *Renewable and Sustainable Energy Reviews*, 71, pp.785-795.

[24] SLoCaT (2018). Transport and Climate Change Global Status Report 2018.
Available at: http://slocat.net/tcc-gsr

[25] Aerosapce Technology (2015). *The 10 biggest cargo aircraft*. [online] Aerospace Technology.
Available at: https://www.aerospace-technology.com/features/featurethe-top-10-biggest-cargo-aircraft-
4589609/#: :text=Boeing%20747%2D8%20Freighter%20%E2%80%93%20447%2C700kg
&text=The%20747%2D8F's%20cargo%20hold,7%2C630km%20(4%2C120nmi).
[Accessed 16 Aug. 2020].

[26] Network For Transport Measures (2018). *Air cargo transport baselines 2018*. [online] Network for Transport Measures.
Available at: https://www.transportmeasures.org/en/wiki/evaluation-transport-suppliers/air-cargo-transport-baselines-2017/ [Accessed 16 Aug.
2020].

[27] Stalpers, S.E., (2020). The environmental impact of Philips' airfreight logistics and improvements using transport mode shift.

[28] Hammond, W., Axsen, J. and Kjeang, E., (2020). How to slash greenhouse gas emissions in the freight sector: Policy insights from a technology-adoption model of Canada. *Energy Policy*, 137, p.111093.

[29] Lister, J., (2015). Green shipping: Governing sustainable maritime transport. *Global Policy*, 6(2), pp.118-129.

[30] Smart Freight Centre, (2018). *Annual Report 2018*. [online] Available at: https://www.smartfreightcentre.org/pdf/SFC-Annual-Report-2018-online.pdf [Accessed 8 July 2020].

[31] Deutsche Post DHL Group, (2020).
The 2019 Sustainability Report. [online] Available at:
https://www.dhl.com/content/dam/dhl/global/core/documents/pdf/sustainability-report.pdf [Accessed 8 July
2020].

[32] Milja, S., Milan, S., Pavle, P. and Zoran, P., (2020). Alternative fuels for public transport vehicles–actual trends. *Trans Motauto World*, 5(3), pp.105-107.

[33] Dubov, G.M., Trukhmanov, D.S. and Nokhrin, S.A., (2020). The Use of Alternative Fuel for Heavy-Duty Dump Trucks as a Way to Reduce the Anthropogenic Impact on the Environment. *E&ES*, 459(4), p.042059.

[34] Aydogan, H. and Acaroglu, M., (2011). The effects of bioethanol-diesel fuel blends on the performance and emissions of a turbocharged pump injection diesel engine. *Energy Educ. Sci. Tech-A*, 28, pp.261-270.

[35] Sutjahjo, D.H., 2018. The characteristics of bioethanol fuel made of vegetable raw materials. *MS&E*, 296(1), p.012019.

[36] Halder, P., Azad, K., Shah, S. and Sarker, E., (2019). Prospects and technological advancement of cellulosic bioethanol ecofuel production. *In Advances in eco-fuels for a sustainable environment* pp. 211-236, Woodhead Publishing.

[37] Dias, D., Antunes, A.P. and Tchepel, O., (2019). Modelling of Emissions and Energy Use from Biofuel Fuelled Vehicles at Urban Scale. *Sustainability*, 11(10), p.2902.

[38] Gnansounou, E., Dauriat, A., Panichelli, L. and Villegas, J., (2008). Energy and greenhouse gas balances of biofuels: biases induced by LCA modelling choices.

[39] Mortimer, N.D., Elsayed, M.A. and Horne, R.E., (2004). Energy and greenhouse gas emissions for bioethanol production from wheat grain and sugar beet. *Resources Research Unit School Of Environment And Development, Sheffield Hallam University, Sheffield.*

[40] DHL (2019). *SUSTAINABLE FUELS FOR LOGISTICS.* [online] *dhl.com.* Available at: https://www.dpdhl.com/content/dam/dpdhl/en/media-center/responsibility/dpdhl-whitepaper-sustainable-fuels-for-logistics.pdf [Accessed 16 Aug. 2020].

[41] Ellis, J. and Tanneberger, K., (2015). Study on the use of ethyl and methyl alcohol as alternative fuels in shipping. *Eur. Marit. Saf. Agency.*

[42] IRENA (2019), *Navigating to a renewable future: Solutions for decarbonising shipping*, Preliminary findings, International Renewable Energy Agency, Abu Dhabi

[43] Hansson, J., Brynolf, S., Fridell, E. and Lehtveer, M., (2020). The Potential Role of Ammonia as Marine Fuel—Based on Energy Systems Modeling and Multi-Criteria Decision Analysis. *Sustainability*, 12(8), p.3265.

[44] Ash, N. and Scarbrough, T., (2019). Sailing on solar: Could green ammonia decarbonise international shipping. *London, United Kingdom.*

[45] Hansson, J., Fridell, E. and Brynolf, S., (2020). On the potential of ammonia as fuel for shipping: a synthesis of knowledge.

[46] Korean Register, (2020). *Forecasting The Alternative Marine Fuel.* [online] pp.8-29. Available at: https://safety4sea.com/wp-content/uploads/2020/01/Korean-Register-Forecasting-the-Alternative-Marine-Fuel-Ammonia-2020_01.pdf [Accessed 29 July 2020].

[47] Baxter, G., (2020). The Use of Aviation Biofuels as an Airport Environmental Sustainability Measure: The Case of Oslo Gardermoen Airport. *MAD-Magazine of Aviation Development*, 8(1), pp.6-17.

[48] Bauen, A., Bitossi, N., German, L., Harris, A. and Leow, K., (2020). Sustainable Aviation Fuels. *Johnson Matthey Technology Review*.

[49] Meyer, K., Weinberg, J. and Kaltschmitt, M., (2012). GHG emissions from jatropha-based bioderived synthetic paraffinic kerosene. *Biofuels*, 3(6), pp.657-674.

[50] Cremonez, P.A., Feroldi, M., de Araújo, A.V., Borges, M.N., Meier, T.W., Feiden, A. and Teleken, J.G., (2015). Biofuels in Brazilian aviation: Current scenario and prospects. *Renewable and Sustainable Energy Reviews*, 43, pp.1063-1072.

[51] Roth, A., (2020). 3 Renewable fuels for aviation. *Aviation and Climate Change: Economic Perspectives on Greenhouse Gas Reduction Policies*.

[52] Han, G.B., Jang, J.H., Ahn, M.H. and Jung, B.H., (2019). Recent Application of Bio-Alcohol: Bio-Jet Fuel. *In Alcohol Fuels-Current Technologies and Future Prospect*. IntechOpen.

[53] Bosch, J.O.N.A.T.H.A.N., Jong, S., Hoefnagels, D. and Slade, D.R., (2017). Aviation biofuels: strategically important, technically achievable, tough to deliver. *Grantham Institute Briefing Paper*, (23).

[54] EPA (2018). Emission Factors for Greenhouse Gas Inventories. [online] Available at: https://www.epa.gov/sites/production/files/2018-03/documents/emission-factors_mar_2018_0.pdf [Accessed 16 Aug. 2020].

[55] Otten, M.B.J., Hoen, M.J.J. and Boer, L.C., (2016). *STREAM Freight Transport 2016: Emissions of Freight Transport Modes*. CE Delft.

[56] Cefic and ECTA, (2011). Guidelines for Measuring and Managing CO2 Emission from Freight Transport Operations.

[57] Airportwatch (n.d.). *AirportWatch — Carbon emissions of air freight compared to other modes of transport*. [online] www.airportwatch.org.uk. Available at: https://www.airportwatch.org.uk/air-freight/carbon-emissions-of-air-freight-compared-to-other-modes-of-transport/ [Accessed 16 Aug. 2020].

[58] Clariant Ltd (2016). *Scania Trucks Use Second Generation Ethanol Manufactured with Clariant's Sunliquid® Technology*. [online] Clariant Ltd. Available at: https://www.clariant.com/en/Corporate/News/2016/05/Scania-trucks-use-second-generation-ethanol-manufactured-with-Clariants-sunliquid-technology [Accessed 16 Aug. 2020].

[59] Novozymes (2018). *The Novozymes Report 2018*. https://report2018.novozymes.com/-/media/Report-site-2018/PDF/The_Novozymes_Report_2018_with_sus.pdf.

[60] Ellis, J., Ramne, B., Bomanson, J., Molander, P., Tunér, M., Aakko-Saksa, P., Svanberg, M., Rydbergh, T. and Berneblad, B. (2018). *SUMMETH – Sustainable Marine Methanol*. [online] Available at: http://summeth.marinemethanol.com/reports/SUMMETH-D6_2-SummaryReport_fnl.pdf [Accessed 16 Aug. 2020].

[61] Formula 1 (2019). *How F1 will lead the charge to use biofuels — Formula 1®*. [online] Formula1.com. Available at: https://www.formula1.com/en/latest/article.how-formula-1-will-lead-the-charge-to-use-biofuels.lxWqy8GilwwMBsjKyPiFf.html [Accessed 16 Aug. 2020].

[62] Alaska Airlines (2016). *Alaska Airlines Flies on Gevo's Renewable Alcohol to Jet Fuel — Alaska Air Group Inc.* [online] investor.alaskaair.com.
Available at: https://investor.alaskaair.com/news-releases/news-release-details/alaska-airlines-flies-gevos-renewable-alcohol-jet-fuel [Accessed 18 Aug. 2020].

[63] Airbus (2010). *TAM Airlines and Airbus first to fly Jatropha-based biofuel in Latin America.* [online] Airbus.com.
Available at: https://www.airbus.com/newsroom/press-releases/en/2010/11/tam-airlines-and-airbus-first-to-fly-jatropha-based-biofuel-in-latin-america.html [Accessed 18 Aug. 2020].

[64] Jha, A. (2008). *Air New Zealand jet completes world's first second-generation biofuel flight.* [online] theguardian.com.
Available at:
https://www.theguardian.com/environment/2008/dec/30/biofuel-test-plane [Accessed 18 Aug. 2020].

Appendix A - Road Freight Emissions Excel Spreadcheet

Road Freight

LNG Properties		*Diesal Properties*	
Consumption (kg/km) =	0,25	Consumption (l /1km) =	0,3
Lower heating value (MJ/kg) =	48,6	Lower heating value (MJ/l) =	36
GHG Emissions (gCO2e/MJ) =	212,22	GHG Emissions (gCO2e/MJ) =	262

Mileage	**Original Route**	**Description**	**Alternataive Route**	
Spain - Monaco (km) =	686	Barcelona - Monte Carlo	Spain - France (km) =	555
France - Austria (km) =	1130	Le Castellet - Spielberg	France - Monaco (km) =	194
Austria - UK (km) =	1579	Spielberg - Silverstone	Monaco - Italy (km) =	337
UK - Germany (km) =	580	Silverstone - Hockenheim	Italy - Austria (km) =	638
Germany - Hungary (km) =	953	Hockenheim - Budapest	Austria - Hungary (km) =	396
Hungary - Belgium (km) =	1219	Budapest - Spa-Francorchamps	Hungary - Russia (km) =	2316
Belgium - Italy (km) =	765	Spa-Francorchamps - Monza	Russia - Germany (km) =	3110
			Germany - Belgium (km) =	310
			Belgium - UK (km) =	407
			Azerbaijain - Bahrain (km)	2237
			Bahrain - Abu dhabi (km)	821

	GHG Emissions			GHG Emissions		
Orig Route	LNG (tonne of CO2e)	Diesal (tonne of CO2e)	**ALT Route**	LNG (tonne of CO2e)	Diesal (tonne of CO2e)	**ALT Route**
Spain - Monaco	1,768832478	1,9411056	Spain - France	1,431052515	1,570428	Spain - France
France - Austria	2,91367449	3,197448	France - Monaco	0,500223762	0,5489424	France - Monaco
Austria - UK	4,071408867	4,4679384	Monaco - Italy	0,868945401	0,9535752	Monaco - Italy
UK - Germany	1,49551434	1,641168	Italy - Austria	1,645065774	1,8052848	Italy - Austria
Germany - Hungary	2,457284769	2,6966088	Austria - Hungary	1,021075308	1,1205216	Austria - Hungary
Hungary - Belgium	3,143158587	3,4492824	Hungary - Russia (km) =	5,971743468	6,5533536	Hungary - Russia (km) =
Belgium - Italy	1,972531845	2,164644	Russia - Germany (km) =	8,01905103	8,800056	Russia - Germany (km) =
TOTAL =	**17,82240538**	**19,5581952**	Germany - Belgium (km) =	0,79932663	0,877176	Germany - Belgium (km) =
			Belgium - UK (km) =	1,049438511	1,1516472	Belgium - UK (km) =
			Azerbaijain - Bahrain (km)	5,768044101	6,3298152	Azerbaijain - Bahrain (km)
			Bahrain - Abu dhabi (km)	2,116926333	2,3231016	Bahrain - Abu dhabi (km)
			TOTAL =	**29,19089283**	**32,0339016**	**TOTAL =**
	% CO2 saved =	**9%**		**%CO2 saved =**	**9%**	

Robustness Assessment

Orig Route	
Spain - Monaco	1,3377
France - Austria	2,2035
Austria - UK	3,07905
UK - Germany	1,131
Germany - Hungary	1,85835
Hungary - Belgium	2,37705
Belgium - Italy	1,49175
TOTAL =	**13,4784**

Weight (tonne) =	15
EF	0,13
% Diff	**31%**

Appendix B - Road Freight Emissions Excel Spreadsheet Continued.

Bio-ethanol		
Consumption (kg/km) =		0,397
Lower heating value (MJ/kg) =		26,8
GHG Emissions (gCO2e/MJ) =		
	Wheat Grain =	44
	Sugar Beet =	47

GHG Emissions			**GHG Emissions**	
Bioethanol Wheat Grain (tonne of CO2e)	Bioethanol Sugar Beet (tonne of CO2e)	**Orig Route**	Bioethanol Wheat Grain (tonne of CO2e)	Bioethanol Sugar Beet (tonne of CO2e)
0,260	0,278	Spain - Monaco	0,321	0,343
0,091	0,097	France - Austria	0,529	0,565
0,158	0,169	Austria - UK	0,739	0,790
0,299	0,319	UK - Germany	0,272	0,290
0,185	0,198	Germany - Hungary	0,446	0,477
1,084	1,158	Hungary - Belgium	0,571	0,610
1,456	1,555	Belgium - Italy	0,358	0,383
0,145	0,155	**TOTAL =**	**3,236**	**3,456**
0,191	0,204			
1,047	1,119			
0,384	0,411			
5,300	**5,661**			

% CO2 saved w//ALT route (Wheat Grain)=	**83%**	**% CO2 saved (Wheat Grain)=**	**83%**
% CO2 saved w// ALT route (Sugar Beet)=	**82%**	**% CO2 saved (Sugar Beet)=**	**82%**

Appendix C - Sea Freight Emissions Excel Spreadsheet

Sea Freight

Known Freight Data:

Weight Sea Freight (tonne) =	500	
Weight Air Freight (tonne) =	660	
	per team	*10 teams*
Team Freight (tonne) =	45	450
Electronics (tonne)	10	100
TOTAL (tonne) =	***55***	***550***
Broadcasting equipments (tonne) =	150	
Hospitality Equipment (tonne) =	460	

Total Air distance for 6 planes (km) =	131.995
Total distance 1 plane (km) =	21.999,17

DHL Carbon Calculator for Shipping

Destination	*Distance (km)*	*gCO2/RTK*	*kgCO2*	*WTW (kgCO2e)*	*Weight (kg)*	*CBM*
UK (LND) - Australia (MEL)	23.955,00	13,62	115.112,32	134.551,82	500.000	1.250
Australia (MEL) - Bahrain	14.844,00	13,26	80.212,82	93.758,70	500.000	1.250
Bahrain - Shanghai	12.653,06	12,58	42.790,77	50.017,02	500.000	1.250
Shanghai (CHINA) - Baku (AZER)	19.392,63	22,75	72.409,68	84.637,80	500.000	1.250
Baku (AZER) - Spain (BAR)	5.458,79	25,24	49.941,20	58.374,98	500.000	1.250
Monaco (MT) - Canada (Quebec)	9.042,00	13,73	42.066,10	49.169,98	500.000	1.250
Canada (QUEB) - France	9.244,43	13,58	40.809,90	47.701,64	500.000	1.250
Italy (MONZA) - Singapore	14.308,84	8,51	43.654,53	51.026,65	500.000	1.250
Singapore - Russia (SOCHI)	14.184,76	11,92	46.834,58	54.743,73	500.000	1.250
Russia (SOCHI) - Japan (SUZUKA)	20.441,66	17,17	67.884,76	79.348,75	500.000	1.250
Japan (SUZUKA) - Mexico (MC)	22.417,32	14,69	85.128,64	99.504,67	500.000	1.250
Mexico (MC) - USA (AUSTIN)	2.192,57	44,18	26.799,18	31.324,88	500.000	1.250
USA (TX) - Brazil	12.742,28	15,84	64.180,34	75.018,74	500.000	1.250
Brazil - Abu Dhabi	18.170,57	16,30	98.842,76	115.534,75	500.000	1.250

ROAD TRANSPORT INCLUDED

TOTAL SHIPPING (tonneCO2e) = 1.024,71

Alternate Route

Destination	*Distance (km)*	*gCO2/RTK*	*kgCO2*	*WTW (kgCO2e)*	*Weight (kg)*	*CBM*
UK - Azerbaijan	9.143,22	30,13	59.834,74	69.939,29	500.000	1.250
Abu Dhabi - Japan	13.919,60	12,83	50.119,74	58.583,67	500.000	1.250
Japan - China	2.017,73	19,06	13.964,99	16.323,32	500.000	1.250
China - Singapore	4.737,83	10,69	20.360,95	23.799,38	500.000	1.250
Singapore - Australia	8.817,15	12,25	37.102,88	43.368,60	500.000	1.250
Australia - Brazil	18.010,64	15,00	97.983,60	114.530,51	500.000	1.250
Brazil - Mexico	12.351,17	19,82	73.685,26	86.128,79	500.000	1.250
Mexico - USA	2.195,35	44,27	26.862,73	31.399,15	500.000	1.250
USA - Canada	8.054,63	50,54	68.102,28	79.603,00	500.000	1.250
Canada - Spain	8.881,24	13,21	38.968,62	45.549,42	500.000	1.250

ROAD TRANSPORT INCLUDED

TOTAL SHIPPING (tonneCO2e) = 569,23

Alternate Route CO2% Saving : 44%

Methanol 25% reduction		
	75%	100,91
		70,32
		37,51
		63,48
		43,78
		36,88
		35,78
		38,27
		41,06
		59,51
		74,63
		23,49
		56,26
		86,65
total		**768,54**

Ammonia 40% and 80% reduction			
	60%	80,73	26,91
	20%	56,26	18,75
		30,01	10,00
		50,78	16,93
		35,02	11,67
		29,50	9,83
		28,62	9,54
		30,62	10,21
		32,85	10,95
		47,61	15,87
		59,70	19,90
		18,79	6,26
		45,01	15,00
		69,32	23,11
total		**614,83**	**204,94**

Diesal (shipping)

Freight Weight (tonne) =	500	Fuel Consumption (MJ/tkm)	0,4987
Lower heating value (MJ/kg) =	42,5	EF (kgCO2/tkm) =	20
GHG Emissions (kgCO2/MJ) =	0,0741		

	CO2 e(Tonne)	CO2e Alt Route (tonne)
UK (LND) - Australia (MEL)	239,55	
Australia (MEL) - Bahrain	148,44	168,9377673
Bahrain - Shanghai	126,5306	257,1901525
Shanghai (CHINA) - Baku (AZER)	193,9263	37,28126428
Baku (AZER) - Spain (BAR)	54,5879	87,54010317
Monaco (MT) - Canada (Quebec)	90,42	162,9130257
Canada (QUEB) - France	92,4443	332,7796235
Italy (MONZA) - Singapore	143,0884	228,2105301
Singapore - Russia (SOCHI)	141,8476	40,56311972
Russia (SOCHI) - Japan (SUZUKA)	204,4166	148,8240695
Japan (SUZUKA) - Mexico (MC)	224,1732	164,0972061
Mexico (MC) - USA (AUSTIN)	21,9257	**1628,336862**
USA (TX) - Brazil	127,4228	
Brazil - Abu Dhabi	181,7057	
	1.990,48	

% Difference 49%

Methanol (shipping)

Freight Weight (tonne) =	500	
Lower heating value (MJ/kg) =	20	
GHG Emissions (kgCO2/MJ) =	0,069	0,0691
Fuel Consumption (MJ/tkm)	0,5189	

	CO2 (tonne)	*CO2 (tonne)*	
UK (LND) - Australia (MEL)	16.528,95	428,84	179.662,50
Australia (MEL) - Bahrain	10.242,36	265,74	111.330,00
Bahrain - Shanghai	8.730,61	226,52	94.897,95
Shanghai (CHINA) - Baku (AZER)	13.380,91	347,17	145.444,73
Baku (AZER) - Spain (BAR)	3.766,57	97,72	40.940,93
Monaco (MT) - Canada (Quebec)	6.238,98	161,87	67.815,00
Canada (QUEB) - France	6.378,66	165,49	69.333,23
Italy (MONZA) - Singapore	9.873,10	256,16	107.316,30
Singapore - Russia (SOCHI)	9.787,48	253,94	106.385,70
Russia (SOCHI) - Japan (SUZUKA)	14.104,75	365,95	153.312,45
Japan (SUZUKA) - Mexico (MC)	15.467,95	401,32	168.129,90
Mexico (MC) - USA (AUSTIN)	1.512,87	39,25	16.444,28
USA (TX) - Brazil	8.792,17	228,11	95.567,10
Brazil - Abu Dhabi	12.537,69	325,29	136.279,28
TOTAL (Tonne) =		**3.563,37**	1.492.859,33
	%CO2 reduction =	**#DIV/0!**	

Liquid Ammonia (shipping)

Freight Volume (m3) =	1250		
Lower heating value (MJ/kg) =	18,6		
GHG Emissions (kgCO2/MJ) =	0,03		
UK (LND) - Australia (MEL)	16.708,61		
Australia (MEL) - Bahrain	10.353,69		
Bahrain - Shanghai	8.825,51		
Shanghai (CHINA) - Baku (AZER)	13.526,36		
Baku (AZER) - Spain (BAR)	3.807,51		
Monaco (MT) - Canada (Quebec)	6.306,80		
Canada (QUEB) - France	6.447,99		
Italy (MONZA) - Singapore	9.980,42		
Singapore - Russia (SOCHI)	9.893,87		
Russia (SOCHI) - Japan (SUZUKA)	14.258,06		
Japan (SUZUKA) - Mexico (MC)	15.636,08		
Mexico (MC) - USA (AUSTIN)	1.529,32		
USA (TX) - Brazil	8.887,74	**TOTAL (Tonne) =**	**126.161,94**
Brazil - Abu Dhabi	12.673,97		

Appendix D - Air Freight Emissions Excel Spreadsheet

Air Freight

Place	lat (deg)	lon (deg)
Destination 1	45,454044	-73,74473
Destination 2	41,296477	2,082994
(lat2-lat1)/2	-0,036281617	
(long2-long1)/2	0,661721724	
A =	0,001315778	
B =	0,377580867	
C =	0,527026076	
D = A + (C*D)	0,200310741	
SQRT(D) =	0,447560879	
distance (km) =	5919,369367	
detour (km) =	142,9054179	
Total Distance (km) =	**6.062,27**	

	Kereosene	Bioethanol	Jatropha SPK
WTW CO2e (kg/tkm) for range >3,600 km=	0,58	0,23	0,37
WTW CO2e (kg/tkm) for range 785 - 3,600 km=	0,92	1,37	0,58
WTW CO2e(kg/tkm) for range <785 km =	2,1	3,27	1,32
Weight (tonne) + Avg 747 Weight =	1056,89		

kgCO2e = Weight * Total Distance * WTW CO2e

Bio Ethanol Properties:

LHV (MJ/kg) =	43,1
kgCO2e/t =	1513,2
SPK JAP seed	
CO2e kg/MJ =	0,07
LHV (MJ/kg)	43,4

reference calc = https://pure.tue.nl/ws/portalfiles/portal/150361054/Master_Thesis_Sophie_Stalpers.pdf

Alternative Route			Distance	
UK	51,470216	-0,512894	4.130,37	4.016.119,01
Azerbaijan	40,464551	50,052466		
Abu Dhabi	24,441632	54,64999	7.979,14	7.758.427,41
Japan	34,863624	136,810798		
Japan	34,863624	136,810798	1.534,06	3.404.798,61
China	31,150616	121,807645		
China	31,150616	121,807645	3.926,28	2.406.794,72
Singapore	1,366801	103,992196		
Singapore	1,366801	103,992196	6.185,16	3.791.479,58
Melbourne	-37,669012	144,840941		
Melbourne	-37,669012	144,840941	13.314,08	8.161.480,45
Brazil	-23,627473	-46,656676		
Brazil	-23,627473	-46,656676	7.597,29	4.657.109,90
Mexico	19,437208	-99,072619		
Mexico	19,437208	-99,072619	1.275,28	781.741,79
USA	30,197063	-97,665967		
USA	30,197063	-97,665967	2.784,88	2.707.846,88
Canada	45,454044	-73,74473		
Canada	45,454044	-73,74473	6.062,27	5.894.580,34
Barcelona	41,296477	2,082994		
			TOTAL AIR CO2e (tonne) =	**43.580,38**

Validation Calculation

Distance	Tonne-km	CO2 (tonne)	Original CO2 (tonne)	% Difference
17.161,61	18.137.933,99	**11980,83092**	10.520,00	**-14%**
12312,22	13.012.662,20	**8595,383887**	7547,35	**-14%**
7003,81	7.402.256,75	**4889,486674**	4293,31	**-14%**
6531,71	6.903.298,98	**4559,90511**	4033,91	**-13%**
4105,28	4.338.829,38	**2865,970358**	2516,52	**-14%**
6291,61	6.649.539,69	**4392,286949**	3856,73	**-14%**
6156,85	6.507.113,20	**4298,208551**	3774,13	**-14%**
10462,11	11.057.299,44	**7303,788571**	6413,23	**-14%**
8009,32	8.464.970,21	**5591,451426**	4909,68	**-14%**
8089,71	8.549.933,60	**5647,573141**	4958,96	**-14%**
11783,49	12.453.852,75	**8226,267893**	7223,24	**-14%**
1275,28	1.347.830,68	**1933,382239**	1240	**-56%**
8262,72	8.732.786,14	**5768,354557**	5065,02	**-14%**
12357,91	13.060.951,50	**8627,280904**	7575,35	**-14%**
5737,22	6.063.610,45	**4005,257244**	3516,89	**-14%**

Original Route	latitude (deg)	longitude (deg)	Total distance (km)	kgCO2e
UK (DHL Express Heathrow)	51,470216	-0,512894	**17.161,61**	**10.520.001,72**
Australia, Melbourne IA	-37,669012	144,840941		
Australia, Melbourne IA	-37,669012	144,840941	**12.312,22**	**7.547.344,07**
Bahrain IA	26,268675	50,625443		
Bahrain IA	26,268675	50,625443	**7.003,81**	**4.293.308,92**
China, Shanghai IA	31,150616	121,807645		
China, Shanghai IA	31,150616	121,807645	**6.531,71**	**4.003.913,41**
Azerbaijan, Baku IA	40,464551	50,052466		
Azerbaijan, Baku IA	40,464551	50,052466	**4.105,28**	**2.516.521,04**
Spain, Barcelona IA	41,296477	2,082994		
Monaco Freight Airport	43,728369	7,415675	**6.291,61**	**3.856.733,02**
Canada, Montreal IA	45,454044	-73,74473		
Canada, Montreal IA	45,454044	-73,74473	**6.156,85**	**3.774.125,65**
France, Marseille Airport	43,437942	5,213817		
Italy, Milan IA	45,456475	9,274271	**10.462,11**	**6.413.233,67**
Sinapore IA	1,366801	103,992196		
Sinapore IA	1,366801	103,992196	**8.009,32**	**4.909.682,72**
Russia, Sochi IA	43,448814	39,941442		
Russia, Sochi IA	43,48814	39,941442	**8.089,71**	**4.958.961,49**
Japan, Central IA	34,863624	136,810798		
Japan, Central IA	34,863624	136,810798	**11.783,49**	**7.223.234,59**
Mexico, Mexico City IA	19,437208	-99,072619		
Mexico, Mexico City IA	19,437208	-99,072619	**1.275,28**	**1.240.004,22**
USA, Austin IA	30,197063	-97,665967		
USA, Austin IA	30,197063	-97,665967	**8.262,72**	**5.065.015,96**
Brazil, Sao Paulo Airport	-23,627473	-46,656676		
Brazil, Sao Paulo Airport	-23,627473	-46,656676	**12.357,91**	**7.575.351,87**
Abu Dhabi IA	24,441632	54,64999		
Abu Dhabi IA	24,441632	54,64999	**5.737,22**	**3.516.894,06**
UK (DHL Express Heathrow)	51,470216	-0,512894		
			TOTAL AIR CO2e (tonne) =	**77.414,33**

Jatropha SPK		Bioethanol	
Original Route CO2e (ton	New Biofuel Saving Value	Original Route CO2e (tonne)	New Biofuel Saving Value
10.520,00	6.627,60	10.520,00	4.234,24
7547,35	4.754,83	7547,35	3.037,76
4293,31	2.704,78	4293,31	1.728,03
4033,91	2.522,47	4033,91	1.611,55
2516,52	1.585,41	2516,52	1.012,88
3856,73	2.429,74	3856,73	1.552,31
3774,13	2.377,70	3774,13	1.519,06
6413,23	4.040,34	6413,23	2.581,29
4909,68	3.093,10	4909,68	1.976,12
4958,96	3.124,15	4958,96	1.995,95
7223,24	4.550,64	7223,24	2.907,31
1240	781,20	1240	1.840,74
5065,02	3.190,96	5065,02	2.038,64
7575,35	4.772,47	7575,35	3.049,03
3516,89	2.215,64	3516,89	1.415,53
77.444,32	**48.771,03**	**77.444,32**	**32.500,44**
% Saving =	**37%**	% Saving =	**58%**